National Park Service
Department of the Interior

Cape Cod National Seashore

Research Opportunities in the Natural and Social Sciences at Cape Cod National Seashore

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This catalog was prepared for Cape Cod National Seashore by
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Message from the Park Superintendent

Since its founding in 1916, the National Park Service has preserved a remarkable and diverse wealth of ecosystems across the country. From forest to desert, mountain to shore, these landscapes offer unparalleled opportunities for recreation, education and research in the physical and biological sciences. As open space and biodiversity continue to decline outside park boundaries, so do our protected park lands grow more precious with every passing day. In the years ahead, our national parks will serve as libraries, living laboratories, and classrooms of tremendous importance for their extraordinary biological and physical diversity and rare vitality.

As with so many of the parks in the National Park System, Cape Cod National Seashore faces increasing pressure from outside (and, due to the complex patterns of land use and ownership within the park, in some cases inside) our boundaries – declining air and water quality, introduction of non-native species, and the fragmentation of woodlands and waterfronts by new development all pose significant challenges to the health of Cape ecosystems. In order to preserve the health and diversity of our natural resources for future generations, we must make an investment, now, in scientific information and management of these treasures. Applying good science to resource management is our best hope for maintaining and restoring the rich natural and cultural heritage found on the outer Cape.

The diversity, complexity and sheer magnitude of wildlife, vegetation and natural processes occurring within the boundaries of Cape Cod National Seashore dictate a collaborative approach to research and resource monitoring at the park. The National Park Service simply cannot meet all of its research needs alone and thus we seek to expand our research partnerships with individuals, universities, public agencies and non-governmental organizations. Together, we can ensure a healthy, sustainable future for the unique natural and cultural resources of outer Cape Cod.

This research catalog contains descriptions of the most pressing scientific research needs within Cape Cod National Seashore, as well as information on application and permitting procedures for interested researchers. The list of projects outlined here is by no means exhaustive, and we strongly encourage interested researchers to develop other projects based on their own interests and expertise. Like the seashore itself, research at the park is diverse and ever changing; please contact us for the most up-to-date information in your area of interest.

Thank you,

Maria Burks, Superintendent
Cape Cod National Seashore

May 7, 2002

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Cape Cod National Seashore

"The sea-shore is a sort of neutral ground, a most advantageous point from which to contemplate this world…."

-- Henry David Thoreau, Cape Cod

Cape Cod – a slender spit of land curving some sixty miles out into the Atlantic Ocean – is an extraordinary resource, a place not only to enjoy the beauties of land, sea and sky or to marvel at the power of a storm-driven ocean, but also to re-energize the spirit. Its striking beaches, ponds, marshes, dunes and forests are matched only by the richness of its human history; as the people of Cape Cod are organically linked to the rhythms of land and sea, so are the people of America linked to the people of Cape Cod. Recognizing the national significance of the outer Cape's natural and cultural landscapes, Congress established Cape Cod National Seashore (CACO) as a unit of the national park system in 1961. Its purpose, then and now, is to provide opportunities for people to experience the outer Cape's incredible natural beauty and unique culture while at the same time protecting its natural and cultural resources for generations to come.

CACO preserves approximately 44,600 acres of uplands, wetlands and tidal areas on outer Cape Cod and contains an exceptional array of coastal communities, including pine-oak forests, heathlands, grasslands, dunes, kettle ponds, cedar swamps, vernal pools, salt marshes, barrier spits and inter-tidal mudflats. These habitats support at least 800 plant and over 500 animal species, including migratory and resident birds, terrestrial and marine mammals, amphibians, reptiles, salt- and freshwater fish, shellfish and other invertebrates. Numerous state, federal and globally rare plant and animal species also exist within the seashore; for many of these threatened and endangered species, CACO represents some of their finest remaining habitat and offers an excellent opportunity for their preservation in the North Atlantic region. As the longest expanse of uninterrupted sandy shoreline on the East Coast, the great Outer Beach further provides outstanding examples of dynamic geomorphic processes. Natural change on the Cape is pervasive and dramatic, especially along the ocean shore. Within the national seashore, the action of wind, waves, tides and rain remains largely unaffected by development, making it unusually easy to observe their effect on the land.

The Cape's prominent position in the Atlantic has long made it a key landmark for human habitation, and archaeological sites testify to over 9,000 years of occupation. By the1600s, the Wampanoag tribes used or inhabited all of the lands now contained within the national seashore and in 1620, the Pilgrims made their first landfall on the shores of the outer Cape. With European settlement, Cape Codders took to the sea, creating a dynamic whaling and fishing industry, as well as a long and famous tradition of shellfishing. The many lighthouses and Coast Guard stations that dot Cape shores reflect this heritage; the beauty and sense of solitude that they have come to represent continues to inspire artists and writers in what is now a centuries-old Cape Cod arts tradition.

Inventory & Monitoring Program

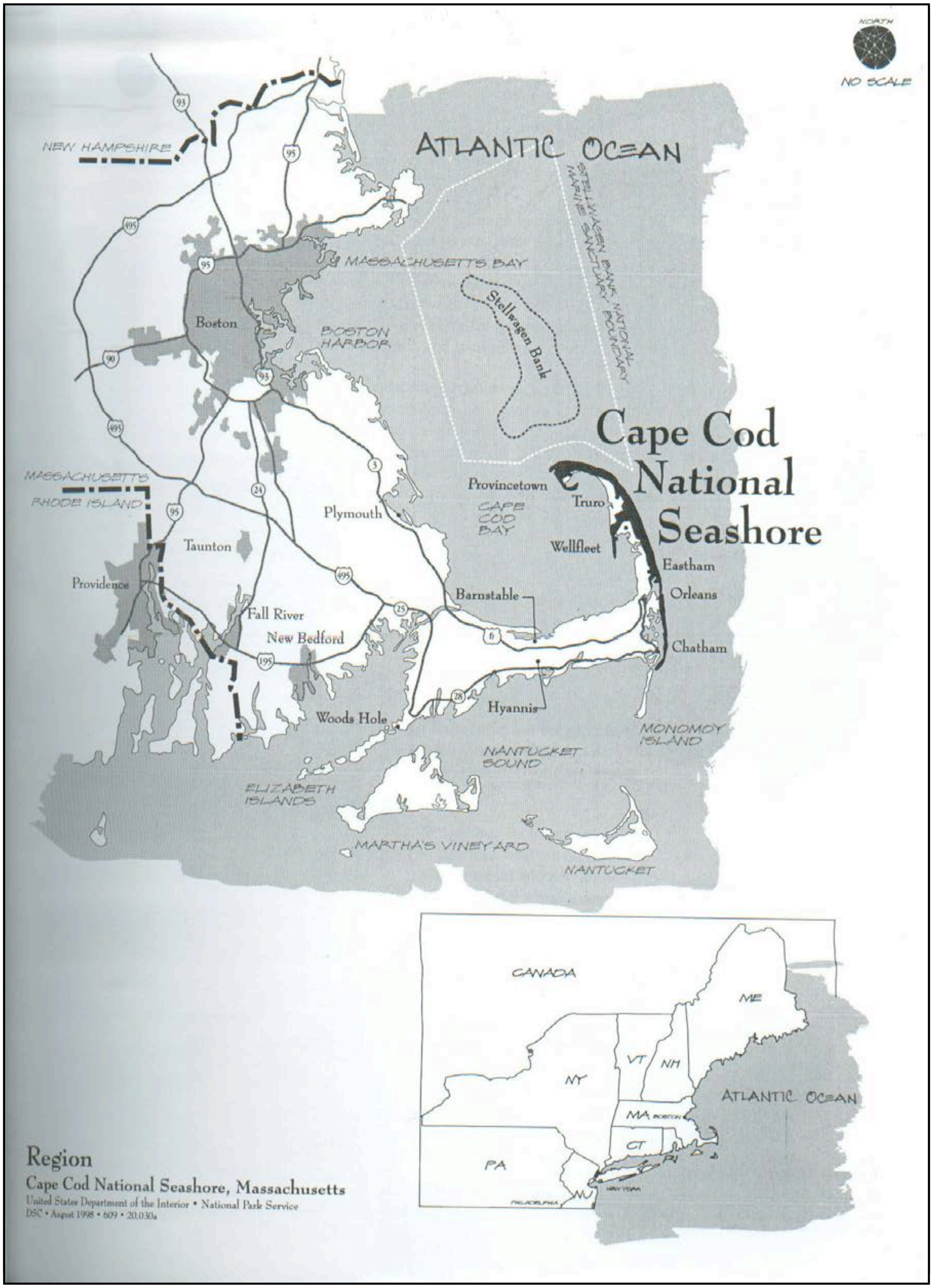
Cape Cod National Seashore's Inventory & Monitoring (I&M) Program was created in 1998 with the understanding that scientifically sound management decisions are crucial to the continued health and diversity of our parks' natural resources, and that identification and ongoing observation of these resources are the foundation of informed, effective management. Natural resource inventories allow managers to account for the presence and distribution of plants, animals and nonliving resources such as water, landforms and climate in the parks, and "vital signs" monitoring enables early detection of potential threats to ecosystem health. As an I&M prototype park, Cape Cod National Seashore serves as a lead in the testing and interpretation of monitoring protocols for Atlantic and Gulf coastal ecosystems and the Northeast Coastal and Barrier Vital Signs Monitoring Network. Inventories of CACO's freshwater fish, small mammal, shorebird, amphibian and reptile communities are underway; water quality, air quality, piping plover (*Charadrius melodus*), and upland forest vegetation monitoring has been initiated, and monitoring protocols are being developed for geomorphic shoreline change, hydrology, invertebrate and plant populations, and other ecological parameters.

Atlantic Learning Center

A sister program to the I&M initiative, the nationwide National Park Service (NPS) Learning Center network aims not only to improve scientific knowledge of park resources, but also to create networks for sharing this information and to educate the American public about the health of our National Park system. By 2005, the NPS intends to create a system of 32 learning centers in a variety of ecosystems across the country; the Atlantic Learning Center at Cape Cod National Seashore was competitively selected as one of the initial five learning center locations. In support of the NPS vision of parks as living laboratories, libraries of knowledge and learning centers for students of all ages, the Atlantic Learning Center (ALC) will house field station lab space for visiting researchers and an adjoining classroom facility on the campus of the Highlands Center at Cape Cod National Seashore. Both ALC buildings are being designed and renovated in partnership with the Federal Energy Management Program, with a focus on environmental sustainability; renovation is expected to be complete in 2003.

Research Application Procedures

A research permit is required for any scientific activity within the park that may disturb resources or visitors, as well as any research involving field work or specimen collection. In order to obtain a permit, interested researchers need to complete a written application and submit it to Cape Cod National Seashore with a research study proposal. It is recommended that interested researchers contact the park prior to developing their proposal (even if it closely resembles one of the projects outlined in this catalog), as specific research needs often change. Applications and more specific information on NPS research procedures and requirements can be found online at *http://science.nature.nps.gov/research*. Inquiries and requests for paper applications should be directed to: Chief of Natural Resources, Cape Cod National Seashore, 99 Marconi Site Road, Wellfleet, MA 02667, phone (508) 349-3785.



Region

Cape Cod National Seashore, Massachusetts

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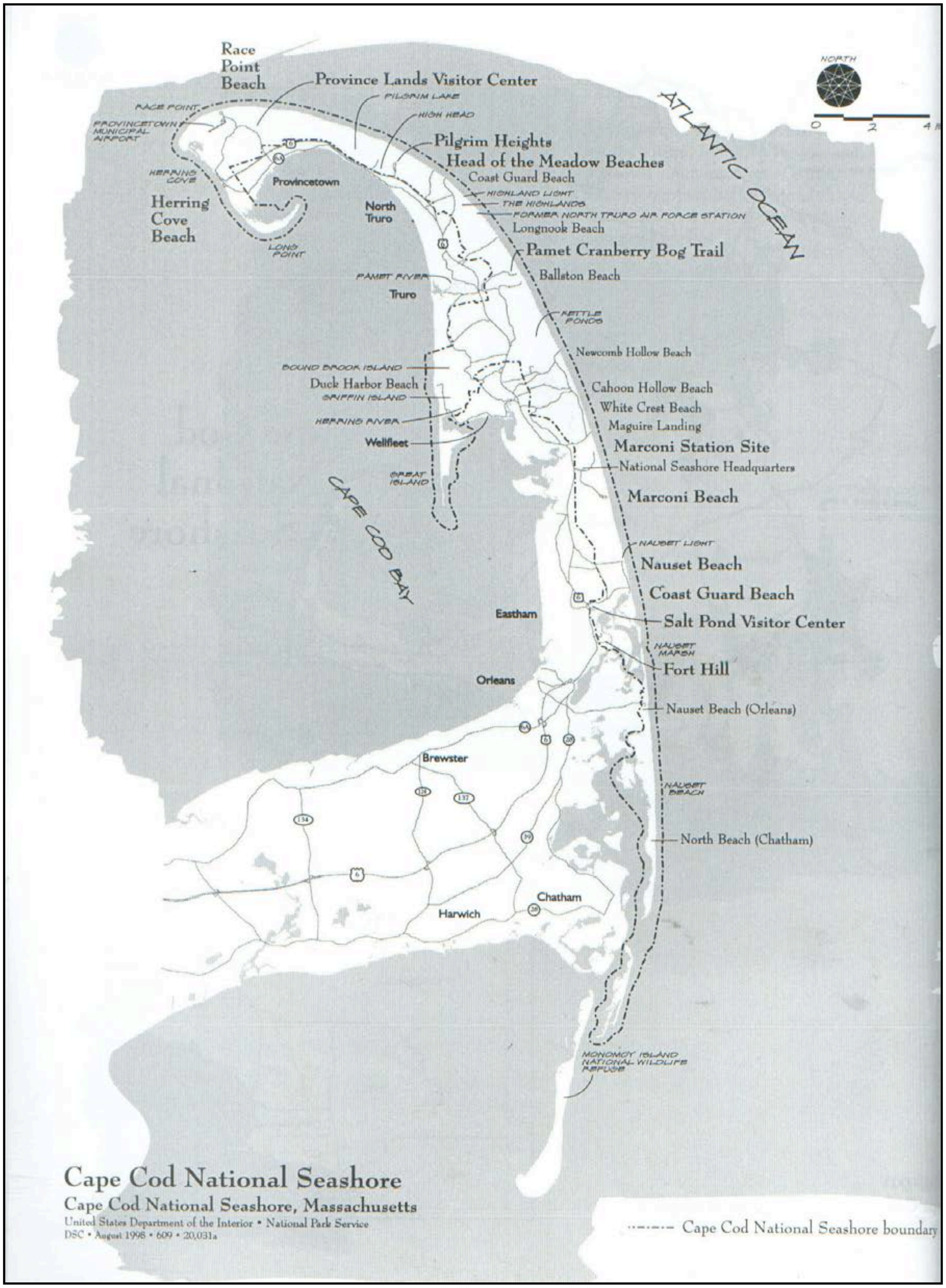
Race Point Beach
Province Lands Visitor Center
PILGRIM LAKE
HIGH HEAD
RACE POINT
PROVINCETOWN MUNICIPAL AIRPORT
HERRING COVE
Provincetown
Herring Cove Beach
LONG POINT
Pilgrim Heights
Head of the Meadow Beaches
Coast Guard Beach
HIGHLAND LIGHT
THE HIGHLANDS
FORMER NORTH TRURO AIR FORCE STATION
Longnook Beach
North Truro
ATLANTIC OCEAN
NORTH
0 2 4
Pamet Cranberry Bog Trail
PAMET RIVER
Ballston Beach
Truro
KETTLE PONDS
Newcomb Hollow Beach
BOUND BROOK ISLAND
Duck Harbor Beach
GRIFFIN ISLAND
Cahoon Hollow Beach
White Crest Beach
HERRING RIVER
Maguire Landing
Wellfleet
Marconi Station Site
National Seashore Headquarters
GREAT ISLAND
CAPE COD BAY
Marconi Beach
NAUSET LIGHT
Nauset Beach
Coast Guard Beach
Eastham
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MONOMOY ISLAND NATIONAL WILDLIFE REFUGE
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Cape Cod National Seashore, Massachusetts
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Cape Cod National Seashore boundary

Aquatic Ecology

Aquaculture Impacts on Estuarine Ecosystems.

Background.

With the decline of the fishing industry and the expansion of aquacultural technology has come an increased interest in managed cultivation of shellfish on Cape Cod. Using natural shellfish habitat to grow seeded shellfish stocks, the Cape's marine aquaculture industry produces substantial harvests of quahogs (*Mercenaria mercenaria*) and Atlantic oysters (*Crassostrea gigas*), as well as small quantities of scallops (*Aequipecten irradians*), soft shell clams (*Mya arenaria*) and blue mussels (*Mytilus edulis*). As interest in the aquacultural use of estuaries and tidal flats within the boundaries of Cape Cod National Seashore increases, so must research on the ecological implications of aquaculture in CACO's estuarine systems.

Research Needs.

Research conducted to date on the ecosystem effects of aquaculture has been limited to studies of effects on sediment and benthic infauna; effects of oyster culture on bird populations have also been minimally addressed, but more comprehensive research is needed to determine the impacts of aquacultural practices on estuarine communities in CACO. The aquaculture "carrying capacity" needs to be determined for each of CACO's farmed areas, and possible long-term impacts to sediment geochemistry and benthic communities need to be more thoroughly explored. The use of intertidal mud flats by other fisheries and by migratory shorebirds in relation to aquaculture operations within CACO should also be investigated, with specific attention to: the selection or avoidance of aquaculture areas by fish (high tide) and migrant shorebirds (low and high tide) during each season; differences in fish and shorebird diversity between open tidal flats and aquaculture areas; temporal and spatial variation of fish and shorebird abundance on open tidal flats and aquaculture areas; and intraseasonal shifts in the use of tidal flats and aquaculture areas as compared with overall abundance changes at specific sites, such as Nauset Marsh and Wellfleet Bay.

(See related project descriptions under "Marsh-Dwelling Shorebirds," in the Wildlife Ecology chapter.)

Coastal Bays and Estuaries.

Background.

Cape Cod's bays and tidal estuaries are among the most biologically productive ecosystems in the world, producing between five and ten tons of organic matter per acre every year. This organic material plays a vital role in the marine food chain of the Northeast Atlantic: the decomposed plant matter that washes into the estuaries from adjacent salt marshes supports algae and plankton, which feed fish, shellfish and insects, which in turn support larger fish, birds, mammals and people. In addition to a number of threatened and endangered plants and animals, it is estimated that two-thirds of the region's commercially important fish and shellfish species spend at least part of their life cycle in an estuary. Seven major marsh and estuarine systems exist within Cape Cod National Seashore, with varying degrees of historic human disturbance and alteration – West End and Hatches Harbor in Provincetown, East Harbor and the Pamet River in Truro, the Herring River in Wellfleet, Pleasant Bay, bordered by the towns of Orleans, Chatham and Harwich, and Nauset Marsh, the most extensive and least disturbed estuary at the seashore, in Eastham.

At CACO and indeed throughout the world, human-induced nitrogen loading is degrading coastal embayments by stimulating massive micro- and macroalgal blooms. Such blooms harm coastal ecosystems by depriving bottom-dwelling plants and animals of the sunlight they need to thrive and by stripping water of oxygen during their decomposition process, creating the potential for massive fish and shellfish kills due to anoxic conditions. Unlike more river-dominated areas, most nitrogen pollution on the Cape enters coastal waters with groundwater from the highly permeable aquifer. Nitrate-nitrogen, primarily from septic wastes, is carried with little attenuation to the shoreline. Although cultural eutrophication of CACO embayments has yet to be demonstrated, groundwater nitrogen values downgradient of developed areas, and immediately upgradient of sensitive surface waters, are often much above normal unpolluted conditions. Upgradient development and sewage disposal continue, with effects that may not reach a critical threshold for some time. Already, however, massive macroalgal blooms occur sporadically in Nauset Marsh and thick epiphytic algal growth suggestive of nutrient excesses occurs on eelgrass in less well-flushed portions of the Nauset system.

A monitoring program was initiated at Nauset Marsh in 1990, as recommended in a Rutgers University study (Roman and Able, 1989). However, this program was discontinued in 1993 due to insufficient funding. Continuation and expansion of this monitoring to include all the estuarine systems at CACO is critically needed for a thorough assessment of the health of, and threats to, outer Cape estuaries.

Coastal Bays and Estuaries, continued.

Research Needs.

Monitor Estuarine Nutrient Enrichment: A protocol for estuarine nutrient enrichment monitoring is currently being developed in partnership with the United States Geological Survey. Upon its completion, monitoring is needed to determine the extent and degree of nitrogen and phosphorous loading into CACO coastal systems via surface runoff and groundwater discharge, and to establish a pattern for such nutrient loading. Ongoing nitrate surveys should be expanded in scope to include ammonium and phosphate, and shoreline surveys should continue to control for high spatial variation, to document seasonal differences and to extend the sampled area. Concurrent studies of macroalgal *Cladophora* production and eelgrass health are required to expose likely indicators of eutrophication. Continuation of this expanded monitoring on a long-term basis is a critical component of local land management and resource protection measures.

Monitor Nekton in Shallow Estuarine Habitats: Because fish and decapod crustaceans are an integral link in the estuarine food web and because they exhibit unique and relatively rapid responses to environmental change, nekton are strong indicators of overall estuarine ecosystem health. As part of CACO's Inventory & Monitoring (I&M) program and in conjunction with the USGS – Water Resources Division, a monitoring protocol has been developed for nekton in shallow subtidal habitats. Long-term monitoring according to this protocol is now needed to address questions related to estuarine habitat restoration and to detect changes, both natural and anthropogenic, in these systems over time.

Monitor Estuarine and Marine Fisheries: Although they are in some cases out of the jurisdiction of the seashore, the health of the outer Cape's marine fisheries is also an important indicator of the condition of CACO's estuarine systems and offshore waters. Research is needed to determine the location and productivity of finfish and shellfish nursery areas at CACO, and the habitat needs and predator-prey interactions of primary fisheries species. Initial investigations should be followed by long-term fisheries monitoring in order to assess changes to CACO's fish populations over time.

Monitor Overall Estuarine Health: Some CACO-wide estuarine monitoring protocols, including salt marsh vegetation, sediment elevation, water quality and the above-mentioned estuarine nutrient enrichment and nekton monitoring, are currently in place or in the process of being developed at CACO for the emerging I&M program. To better understand the dynamic nature of estuaries on the outer Cape and the numerous threats to these systems, however, all aspects of the intensive long-term monitoring program that was initiated for Nauset Marsh in 1990 need to be resumed for all estuarine systems within the park. Investigations of the impacts of adjacent land-use on marine habitats should continue for eelgrass, *Cladophora* and anoxic deep-water zones, and other macroalgae should be sampled at Nauset Marsh to determine changes in species composition since the original Rutgers University report. Specific parameters to be monitored include temperature and salinity, eelgrass wasting disease indices, algae biomass on mudflats and species occurrence in tidal channels.

Coastal Bays and Estuaries, continued.

(See "Estuarine Habitat Restoration" for related project descriptions.)

Research Cited.

Roman, C. and K. Able. 1989. An ecological analysis of Nauset Marsh, Cape Cod National Seashore. NPS CRU, Rutgers University, New Brunswick, NJ.

Aquatic Ecology

Estuarine Habitat Restoration.

Background.

Salt marshes are one of the most productive ecosystems in the world, producing between five and ten tons of organic matter per acre every year. Much of this organic material is not consumed directly by marsh wildlife, but is instead washed into tidal estuaries, where it plays a vital role in the food chain: the decomposed plant matter supports algae and plankton, which feed fish, shellfish, and insects, which in turn support larger fish, birds, mammals and even people – over two-thirds of commercially important fish and shellfish spend at least part of their life cycle in a salt marsh. Marshes also serve as protective barriers during hurricanes and winter storms, absorbing much of the rising seawater and heightened wave energy that would otherwise batter coastal areas, and they protect the health of coastal waters by absorbing nitrogen, which leaks into the water supply from septic systems.

Unfortunately, fifty percent of the nation's coastal wetlands have been destroyed and even more have been significantly impacted by human activity (Roman et al., 1995a). Many of the marshes within Cape Cod National Seashore have been altered by dikes and/or tide gates and subsequently drained. This practice of "marsh reclamation" dates back to the late-1600s and was meant to reduce mosquito populations, increase productive agricultural acreage and improve roadways (Portnoy and Soukup, 1988). Although mosquitoes in many diked areas remain abundant, much native habitat has been lost as a result of the diking.

The National Park Service has been conducting research on tide-restricted areas since 1980 in an effort to document the dramatic alteration of plant and wildlife habitat caused by the restriction of seawater flow into salt marshes (Soukup and Portnoy, 1986; Portnoy and Giblin, 1997). Salt marshes require sediment input from the ocean in order to remain elevated above sea level rise. Dike structures prevent this process from occurring, causing such marshes to be vulnerable to flooding when dikes are breached. Additionally, salt marsh peat left after the marsh is drained periodically releases toxic acids and aluminum as it decomposes, resulting in the potential for massive fish kills (Soukup and Portnoy, 1986). Diking also reduces and sometimes altogether eliminates tidal flushing of nitrogen from salt marsh estuaries, leading to eutrophication and potential oxygen depletion. Constant summertime oxygen stress from lack of tidal flushing reduces both fish and invertebrate numbers and diversity in diked and drained wetlands (Portnoy, 1991).

Estuarine Habitat Restoration, continued.

Restoration of salt marshes provides resource managers with a valuable tool for maintaining and enhancing coastal zone habitat diversity. Numerous studies in other regions have shown that degraded coastal wetlands and small estuaries can be successfully restored, using pre-restoration hydrologic modeling to predict tide height levels and tidal flooding elevations that may occur as a result of restoration (Roman et al., 1995). There are three estuary systems and one coastal lagoon currently in various stages of consideration for tidal flow restoration within CACO: the Herring River in Wellfleet, Hatches Harbor in Provincetown, and the Pamet River and Pilgrim Lake in Truro.

Herring River. The 5-kilometer long Herring River is part of a 405-hectare salt marsh estuary system that has been dramatically altered by humans over the last 150 years. Tidal flow in the Herring River was initially modified by the construction of a railroad through the area in the 1850s and was further reduced in 1908 by a dike built at Chequesset Neck to allow mosquito control drainage and to create arable land. Salt hay and fish production decreased as a result of this dike; the mosquito nuisance, however, did not. Abundant breeding of freshwater and brackish species (*Aedes sollicitans, A. cantator*) continued in the stagnant water behind the structure, leading to extensive ditch drainage of the freshened marshes beginning in 1910 and culminating in the channelization and straightening of the main stream and tributary creeks in the early 1930s. By the late 1960s, the dike had gradually deteriorated, allowing increased tidal flow and re-colonization of oysters and soft shell clams in previously freshened portions of the estuary. This return of shellfish to the area spurred local public support to remove the dike and restore tidal flow to the system. Despite great opposition, however, the original dike was rebuilt in 1975 by the state, this time with specific requirements imposed by the town conservation commission for a minimum amount of tidal flow through an adjustable gate in the structure. These water levels were not achieved until CACO staff demonstrated a shortfall in the dike's operation to the state attorney general's office in 1981. Though present tidal flow approaches those prescribed by the town's Order of Conditions, serious biogeochemical disturbance remains.

Since 1980, CACO has conducted extensive studies of the hydrology, chemistry and biology of the Herring River system. This work was initially prompted by a series of massive kills of alewife (*Alosa pseudoharengus*) and blue-backed herring (*Alosa aestivalis*), anadromous species that annually spawn in the kettle ponds at the river's headwaters. Over the past ten years, CACO has shown that reduced tidal flushing and seawater excursion into the estuary, and increased salt marsh peat oxidation due to drainage, have lead to sulfate oxidation, surface water acidification and, perhaps most seriously, the seasonal oxygen depletion responsible for the massive fish kills in the early 1980s. Cooperating scientists quantified the loss of estuarine habitat due both to reductions in salinity and flooding frequency, and to vegetative shifts from *Spartina* cover to *Phragmites*, freshwater wetland and even upland plant species. Rutgers University researchers modeled the full range of dike opening alternatives and predicted major ecological and social benefits for restored tidal flow.

Estuarine Habitat Restoration, continued.

As mentioned above, dikes were historically constructed in order to reduce and eliminate saltwater mosquito habitats. Studies have found, however, that mosquito populations continue to thrive in the presence of dikes (Portnoy, 1984). Surface water acidification by high sulfate limits fish populations, which are natural predators of mosquitoes, and acid-tolerant mosquitoes are favored in the stagnant waters behind the structures. Based on this information, Portnoy (1984) has predicted that in addition to an increase in typical marsh-estuarine vegetation, a decrease in stream anoxia and acidification and a restoration of fish habitat and shellfish populations, restored tidal flushing will also produce an actual decline in mosquito populations. The restoration of the Herring River provides a unique opportunity to test this hypothesis.

Restoration of the Herring River will involve a number of government and private entities, including the Town of Wellfleet, which holds the title to the dike, the state Department of Environmental Protection, which has control of the valves within the structure and has regulatory authority over adjacent wetlands, the Chequesset Yacht and Country Club, a local golf course expected to be affected by increased water levels after restoration, two private homeowners also within the floodplain and CACO.

<u>Hatches Harbor</u>.

Prior to 1930, Hatches Harbor was a productive 200-acre salt marsh and open water embayment. Since then, at least 100 hectares of the Hatches Harbor coastal floodplain and salt marsh system have been isolated from tidal exchange by a dike. Originally constructed to drain the landward half of the wetland for mosquito control, the structure's sole present purpose is to provide flood protection for a municipal airport. National Park Service research has shown, however, that the complete diking of tidal flow is not necessary in order to protect the airport from occasional storm tides. Bathymetric surveys, tide height studies and modeling have indicated that a substantial area of the original marsh can be restored by reintroducing tidal flow through enlarged culverts in the dike structure, with no impact to the airport.

A conceptual restoration and monitoring plan was accepted by all ten local, state and federal agencies with interests in either airport operations or local land management, including wetland protection, and the construction of new culverts to allow increased tidal flow was completed in 1999. The culverts are now being opened incrementally, and preliminary data has indicated that the increased tidal flow is positively affecting estuarine fish use and native salt marsh vegetation.

<u>Pamet River</u>.

Pamet Harbor, located on Cape Cod Bay, was once a viable commercial port that served a large fleet of local fishing vessels operating in the cod and mackerel industry (Giese et al., 1993 and 1985). During the mid-1800s, commercial fishing fleets competed for space to anchor in the harbor and residents began to alter the hydrology of the Pamet in

Estuarine Habitat Restoration, continued.

hopes of increasing the harbor's capabilities (Giese et al., 1985). From 1850 to 1930, much of the estuary was diked and dredged. Wilder's Dike was built in 1869 to replace a rotting bridge across the mid-section of the Great Pamet River and in 1950, a clapper valve and dike structure were built to accommodate the construction of Route 6 (Giese et al., 1993).

The diking of the Pamet established two distinct hydrological reaches, the Upper Pamet and the Lower Pamet. East of the tide gate located just west of Route 6, the Upper Pamet is freshwater with a watershed encompassing approximately 192 acres. Many upland species of salt-intolerant plants have invaded the area. Precipitation and groundwater discharge from the Pamet and Chequesset lenses are continually recharging this section of the Pamet, which flows slowly west into the Lower Pamet, a salt marsh estuary (National Park Service, 1986).

The Lower Pamet is an intertidal estuary, greatly stressed by past alterations that have reduced natural tidal circulation and in turn increased shoaling and sedimentation (Giese et al., 1993). Tidal channel beds, except for the outermost section of the inlet channel, are higher than mean low tide in Cape Cod Bay. Restoring tidal flow to the Pamet River is expected to increase natural flushing in the estuary, which would in turn improve water quality, maintain habitat diversity and balance sediment loads in the Pamet River Valley. Additionally, restoration of natural flows would allow the salt marsh to regain a state of equilibrium between sea level and wetland elevations in the Upper Pamet.

<u>Pilgrim Lake</u>.

Pilgrim Lake is a 291-hectare coastal lagoon that functioned as a tidal back barrier estuary and salt marsh before it was isolated from Cape Cod Bay in 1868, purportedly to prevent sand from filling Provincetown Harbor. After this effective diking, the system freshened with current salt levels at about 6.8 parts per thousand (ppt), or 20 percent of seawater levels. Sand from the migrating dunes to the northwest has apparently shoaled the impounded "lake" to an average depth of 1.3 meters, and the waters are hypereutrophic with large blooms of nitrogen-fixing, blue-green bacteria.

In 1956, nuisance mosquito problems prompted the state to install a drainage system consisting of a weir at High Head Road and a culvert carrying water from Pilgrim Lake under Routes 6 and 6A to discharge into Cape Cod Bay. With two flap valves in the culvert to prevent seawater from entering the lake at high tide, the system was intended to lower the level of the lake, thereby reducing the extent of floodwater mosquito breeding sites in surrounding wetlands. Minimum lake level was determined by the height of the weir boards. The complexity of management, and the lack of a scientifically-based management plan, was demonstrated in 1968 when reductions in the lake level for mosquito control resulted in a massive kill of introduced carp and other fish, apparently due to low oxygen and perhaps high salinity. Shortly thereafter, chironomid midges emerged in large numbers, impacting a local tourist trade. Although not an approved activity now, the lake was sprayed with the organophosphate Abate,

Estuarine Habitat Restoration, continued.

potentially killing other beneficial invertebrates as well as midges. Whether the change in lake level, the removal of predatory fish, or changes in lake or sediment chemistry was the cause of the midge problem was never determined; however, this experience discouraged further manipulations of lake level or experiments in restoring seawater flow. Recent review of the midge emergence (J. Portnoy, unpublished report 1991) suggests that the outbreak may have been more directly related to the water drawdown, and not to the release from fish predation pressures.

A fish kill of over 30,000 juvenile alewives and hundreds of white perch in September 2001, likely due to oxygen depletion resulting from the lack of tidal exchange in the Pilgrim Lake system, prompted an experimental opening of the tide gates beginning in December 2001. Tide height and salinity monitoring was conducted prior to the opening of the gates and will continue with the gates open; if salinity remains below 10 ppt over most of the "lake," the gates will remain open indefinitely. A detailed hydrodynamic assessment of the Pilgrim Lake system is still critically needed, however, in order to develop a more comprehensive program for possible estuarine restoration.

Research Needs.

<u>Herring River.</u>

Monitor Herring River Dissolved Oxygen: In order to mitigate further die-offs, a fish gate was constructed in 1986 at the outlet of the Herring Pond in Wellfleet. The gate is used in the summer to block downstream passage of juvenile fish until adequate oxygen levels return to the river. Dissolved oxygen levels are monitored three time a week in the summer at a permanent sampling station within the Herring River. When anoxic conditions are identified (dissolved oxygen of 3 ppm or less), the fish gate is closed. Once dissolved oxygen in the river has returned to above lethal levels, the gate is re-opened. Continued seasonal monitoring is required in order to both ensure the health of CACO's native anadromous fish populations and to track long-term changes in the water quality of the Herring River.

Monitor Ecological Changes Resulting from Restoration: CACO and cooperators have established a detailed description of this estuary's biological, physical and chemical environment over the past ten years of research. As tidal flow is returned, tide heights, water quality, wetland vegetation, benthic invertebrate populations, salt-fresh groundwater relationships, mosquito populations and aquatic fauna need to be regularly monitored for change. Given the adjustability of the dike structure, such ecological changes will likely require measurement in small increments. This strategy will also provide an opportunity for an experimental analysis of the hydrological and geochemical effects of sea level rise, as projected with global warming.

Estuarine Habitat Restoration, continued.

Hatches Harbor.

Cape Cod National Seashore staff have been amassing physical, biological and water quality data on the Hatches Harbor system since 1987 in preparation for what has been described as "the largest single wetland restoration project in the history of Massachusetts" (Portnoy, 1990). In 1999, CACO began incrementally opening the new enlarged culverts, and post-restoration monitoring for changes in hydrology and wetland vegetation was initiated. Continued long-term monitoring of ecological changes following restoration is now needed.

Pamet River.

Historic monitoring of the Pamet River includes elevation surveys and some salinity studies after the barrier beach overwashed in 1991 and 1992. The overwashes made it clear that although this system is diked, it still functions as a back-barrier wetland. Retention of seawater between the overwashed dune and the dike highlighted the inadequate size of present culverts for water discharge. Proposals to restore the Pamet River prompted a recently completed U.S. Army Corps of Engineers study (Kedzierski et al., 1998) of culvert alternatives, which predicts the hydrological, ecological and social effects of tidal restoration. Nevertheless, monitoring is still necessary to assess the system's current functions and values as freshwater wetland habitat and to further evaluate the need for tidal restoration. Especially important is the question of *Phragmites* spread on the floodplain. This invasive grass is well-established in the Pamet River floodplain and could form a monoculture, particularly if present freshwater vegetation is stressed by occasional overwashes of seawater. Monitoring should concentrate on topography, vegetation, soil conditions, hydrology and surface water chemistry.

Pilgrim Lake and Salt Meadow.

An intensive investigation of the physical processes attendant to returning tidal flow to Pilgrim Lake and Salt Meadow is needed, and should include:

1. a description of the system's current tidal and salinity regime, including an assessment of control structures (i.e. culverts, clapper valves and the weir) relative to lake hydrology, hydrography and salinity;
2. topographic and sediment mapping -- detailed topographic data should be collected for the entire floodplain and barrier beach system. Manmade structures (i.e. culverts, weirs and roadways) within the floodplain should also be surveyed, and sediments should be sampled throughout the lake and ditch drainage system for grain size, organic content and resistance to erosion;
3. numerical modeling of the present hydrodynamics and sedimentation; and
4. recommendations for potential tidal restoration scenarios, including modeling and assessment of their physical effects (tide heights, salinity distributions and sedimentation).

Estuarine Habitat Restoration, continued.

(See "Coastal Bays and Estuaries" for related project descriptions.)

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Groundwater Withdrawal.

Background.

The surface freshwater and estuarine resources of Cape Cod National Seashore are dependent upon several thin lenses of fresh groundwater floating atop a base of saltwater beneath the Cape peninsula. The thickness of each freshwater lens varies according to its soil composition (e.g. grain size), depth to bedrock, rate of recharge from precipitation and the width of the Cape at each point in the lens. Hydrogeologically separated from one another by tidal rivers that cut across the Cape, the Pilgrim, Pamet, Chequesset and Nauset lenses are vital to sustaining the outer Cape's cultural and ecological resources. They are the outer Cape's sole source of potable water, and the only hydrologic resource for freshwater dependent flora and fauna.

The only source of freshwater to the lenses in the outer Cape aquifer is precipitation (40"- 47" per year). Just under half of the yearly rainfall (18"- 22" per year) infiltrates the aquifer and recharges the groundwater system. Precipitation that is not recharged to the aquifer evaporates or is transpired by plants. (Surface runoff is negligible because of the highly permeable soils of the Outer Cape.) A great percentage of the recharge passes slowly through the aquifer and is discharged into the surrounding ocean; every day, millions of gallons of fresh groundwater seep out of the ground directly into estuaries and eventually into the ocean, where they help to regulate water chemistry (Cape Cod Planning and Economic Development Commission 1978)

Under natural hydrologic conditions, the freshwater and saltwater flow systems are assumed to be in hydrodynamic equilibrium: groundwater discharge from the freshwater aquifer is balanced by recharge from precipitation, resulting in a static interface between the two flow systems. Decreases in aquifer recharge or increases in groundwater pumping may however decrease the rate of coastal freshwater discharge, creating a landward movement of the boundary of the freshwater lens.

Significant growth in the number of summer and permanent residents on Cape Cod has dramatically increased groundwater use during the past thirty years, placing stress on groundwater resources (Persky, 1986). Substantial local withdrawals of groundwater, e.g. municipal well fields, result in lateral zones of depression on the water table, with the greatest effect occurring upgradient of the withdrawal site. Any wetlands within this affected zone thus experience an artificially lowered water table. Because of the relative densities of fresh and salt water, the depth of the fresh lens at any location is about forty times its height above mean sea level. This relation dictates, for example, that an artificial depression of the water table created by pumping merely two feet will result in an 80-foot upconing of salty seawater into the naturally fresh groundwater lens. Such chronic lowering of surface waters in emergent wetlands may produce major shifts in floral dominance and can also limit flooded habitat for dependent aquatic fauna. In addition, the effects of prolonged pumping have been shown to be cumulative.

Groundwater Withdrawal, continued.

With increasing permanent and seasonal populations comes a need to expand public water supply capabilities and indeed some areas not currently being served by public water supply systems will need to develop systems in the future as a result of water quality concerns. Research on the extent and impact of long-term declines in groundwater, pond and wetland levels, in the quantity of streamflow and in the possibility of saltwater intrusion from the surrounding ocean is critical for water resource management decisions, both now and in the future.

Research Needs.

Research is currently being conducted by the United States Geological Survey-Biological Resources Division, National Park Service, Cape Cod Commission and Massachusetts Audubon Society on the potential hydrological, biogeochemical and ecological effects of municipal groundwater withdrawals at vernal ponds, kettle ponds and littoral zones. The hydrologic environment has been described and modeled, and several rounds of vegetation, aquatic invertebrate and chemical sampling have been completed. Expansion of the current sampling areas to include the Atlantic white cedar swamp and interdunal ponds, and long-term monitoring of all sampling sites is needed for an accurate evaluation of groundwater withdrawal impacts on surface groundwater systems.

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The Gull Pond Sluiceway.

Background.

During the 1800s, Wellfleet residents dug and stabilized an artificial sluiceway between Gull and Higgins ponds in order to provide herring with additional spawning waters in Gull Pond, thereby expanding the existing Herring River anadromous fish run. The National Park Service has been maintaining the sluiceway with periodic dredging since the establishment of Cape Cod National Seashore in 1961 and has recently allowed this practice to be taken over by local volunteers working under the direction of the Massachusetts Herring Run Protection Program. Traditionally, NPS has maintained the sluiceway for fish passage, and because little is known about the effects on Gull Pond of allowing the sluiceway to fill in. While the sluiceway remains a part of the cultural landscape of Cape Cod, a National Seashore management objective requiring CACO management to "allow natural processes to continue unimpeded in natural zones . . . and neutralize the effects of human intervention where it has adversely affected natural systems" clearly contradicts the current sluiceway preservation efforts. Whether or not to continue maintaining the historical sluiceway between Gull and Higgins ponds is a complex question with potential impacts on the natural biota of the ponds, the introduced trout fishery in Gull Pond, the anadromous herring run in the Herring River, and Gull Pond water quality.

Without the flow of surface water provided by the sluiceway, mature alewives (*Alosa pseudoharengus*) and blue-backed herring (*Alosa aestivalis*) would no longer be able to enter Gull Pond to spawn in the spring and juveniles of the species would be unable to leave the pond for their migration to the sea in the summer and fall. The present influx of these fish into Gull Pond may have a considerable impact upon its food chains and nutrient cycles. Adult fish remain at their spawning grounds anywhere from a few days to many weeks and, while there, mortality may reach as high as 57 percent (Durbin et al., 1979). Additionally, young alewives spend part or all of their first summer in the nursery area before migrating seaward. Since most of their growth and nutrient uptake occurs at sea, these fish may represent a significant nutrient source to their freshwater spawning and nursery grounds (through shedding of eggs and sperm, excretions and the carcasses of dead spawners). Such nutrient additions may be particularly pronounced in slow-flushing, groundwater-fed ponds like Gull Pond, which has a residence time of 10-15 years (Mitchell and Soukup, 1981).

Alewives can also considerably alter an existing aquatic community of plants and animals through their role in the food chain. Alewives are planktivores, fish that eat zooplankton. Zooplankton are herbivores that feed on algae in lakes and ponds and, in turn, reduce the amount of algae present there. When planktivores such as the alewife are introduced to a pond, zooplankton decrease and algae increase with the reduced grazing pressure (Shapiro, 1990). Based on this occurrence, which has been observed in several locations including Lake Michigan (Shapiro, 1990), Gull Pond would hypothetically see a decrease in algal growth after the sluiceway is closed and herring are prevented from entering.

The Gull Pond Sluiceway, continued.

Current levels of algal density may be a factor in the relatively low clarity observed in Gull Pond. Reduced clarity may, in turn, contribute to the dissolved oxygen deficit observed at the bottom of the pond by reducing the level of light penetration at this depth and increasing the deposition of organic matter to the bottom. This change may eventually affect, among other things, the trout fishery managed by the Massachusetts Division of Fisheries and Wildlife in the pond (Mitchell and Soukup, 1981).

Research Needs.

History and ecology are highly interconnected on the issue of maintaining the sluiceway to Gull Pond. From a historical perspective, the nearly 200-year existence of the sluiceway (Winkler, 1994) is a strong argument that it should be maintained, just as other historic structures are maintained in the park. From an ecological perspective, the sluiceway is neither natural nor self-maintaining, as natural processes would cause it to fill in. Determining whether or not it creates an overall ecological benefit to the entire Herring River ecosystem is critical to deciding whether or not to continue sluiceway maintenance. As outlined in CACO's Water Resources Management Plan (Godfrey et al., 1999), a detailed nutrient budget for Gull Pond and the freshwater reach of the Herring System (see the related project under "Kettle Ponds") and research into the trophic structure of Gull Pond and the chain of ponds, river and estuary downstream are needed in order to understand the full ecological impact of the sluiceway. Most of the research effort should focus on Gull Pond itself, under the assumption that the anadromous fishery in downstream lakes and flowing systems would not change significantly if the sluiceway was allowed to fill in. However, sufficient data should be collected to verify that assumption. Standard procedures for determining a nutrient budget by measuring all inputs and outputs should be followed. Measurements of watershed inputs and outputs will necessarily focus on groundwater flow and outlet loss, and anadromous fish should be counted as a net input, necessitating counts and average size estimates for incoming and outgoing fish. Trophic structure analysis will require collection, identification and counting of phytoplankton and zooplankton at least once a month.

Additionally, if the nutrient contribution of the anadromous run is found to be large and if the trophic structure does appear to be skewed in ways typical of herring grazing on zooplankton, a study modeling the effect of removing the herring run from Gull Pond will need to be completed. Model development should reflect the steady-state endpoints of both changes in biomass and qualitative characteristics (gross species composition), as both are key to determining ecological benefit.

When a management decision is made to either maintain the sluiceway or to let it close naturally, a monitoring program should be initiated with sufficient detail to reveal changes prior to ecological effects becoming irreversible.

The Gull Pond Sluiceway, continued.

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Inter-Dune Wetlands.

Background.

The parabolic dunefields of North Truro and Provincetown contain numerous depressions, some of which reach down to the water table to form shallow wetlands that serve as "oases" within the larger dune complexes. Though quite variable in extent and composition, these dune slack ponds and wetlands support a distinct and highly diverse plant community and provide vital sources of freshwater and forage for wildlife. The interdunal bogs have been field surveyed for the presence of state-listed plants, and are described as being unusual because of their species diversity and community type (LeBlond, 1990). Preliminary surveys also suggest that these wetlands are an important breeding habitat for the Eastern spadefoot toad (*Scaphiopus holbrookii*), a Massachusetts state threatened species, and that the Province Lands in general support what may be the largest concentration of this species in the state. These interdunal wetlands may additionally serve as seed sources for vegetation throughout the Province Lands, and as such are particularly vital to the natural revegetation of dunes via primary succession. These relatively small and scattered ecosystems thus provide crucial ecological services for overall landscape processes as well as endangered species within Cape Cod National Seashore.

Intensive development in Provincetown has put increasing demands on groundwater resources in the Province Lands area. As municipal wells and wastewater treatment facilities are installed adjacent to CACO boundaries, serious concerns are arising over the potential effect these water table modifications may have on dune slack wetlands. Additionally, re-routing of administrative and private landowner access roads has conflicted with the preservation of these sensitive wetlands in recent years. A major portion of the Province Lands has been designated a historic district on the National Register of Historic Places, and the relocation of dune shacks within that district may also be a future management issue. Our ability to protect these wetlands and the species that rely on them is at present severely hampered by a lack of baseline data on their spatial distribution and water quality.

Research Needs.

Map Bog Locations: The dune wetlands within Cape Cod National Seashore are not always detectable on USGS maps and have not yet been mapped by other means. These areas need to be mapped for incorporation into CACO's Geographic Information System, and existing data on state listed rare plants incorporated into a relational database for use in determining road and residence relocation, revegetation sites, etc.

Inter-Dune Wetlands, continued.

Monitor Water Quality: Monitoring of dune bog water quality, both immediately and on a long-term basis and in conjunction with the past paleo-limnological study of the Provincetown area water bodies (Winkler, 1990), is critically needed.

Develop and Implement Monitoring Program: Development and implementation of an inventory and monitoring plan for these wetlands, analogous to the plans for CACO's estuarine resources and kettle ponds, is needed in order to document the current composition of their flora and fauna and to track future changes in CACO's interdunal plant and animal communities.

Evaluate Groundwater Drawdown Impacts: Given the obvious dependence of Province Lands flora and fauna on dune slack wetlands and the permanence of municipal wells and wastewater facilities, the potential for making a lasting and irreversible impact to the Province Lands systems is severe without basic data on their expected response to these groundwater modifications. Once baseline inventories of the biotic and abiotic components of CACO's dune slacks have been completed, investigations into the impacts of groundwater drawdown on inter-dune wetland hydrology, and the associated effects on plants and wildlife, are critically needed.

(See related project descriptions under "Groundwater Withdrawal.")

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Invasive Aquatic Species.

Background.

Given the proximity of Cape Cod National Seashore to the major shipping ports of Boston and

New York and the major role that ballast waters have played in the introduction of non-native species to North America, it may not be surprising that a number of invasive aquatic species have taken hold in Cape waters. The European green crab (*Carcinus maenas*), a widely-distributed invasive that feeds voraciously on both bivalves and the larvae of other crab species, has the potential to restructure the outer Cape's crab population and to devastate near-shore crustacean and invertebrate nurseries. The Japanese shore crab (*Hemigrapsus sanguineus*) may also crowd out native marine species and pose a threat to local shellfisheries, and common carp (*Cyprinus carpio*), an Asian freshwater species, has contributed heavily to the anoxic conditions of Pilgrim Lake in Truro. Green fleece (*Codium fragile*), an invasive marine algae, is adversely affecting shellfish populations throughout the seashore and Japanese knotweed (*Polygonum cuspidatum*), a quick-spreading introduced wetland weed resistant to eradication, occurs just outside CACO boundaries in Provincetown. Water hyacinth (*Eichhornia crassipes*), purple loosestrife (*Lycopodium sabinifolium*) and common reed (*Phragmites australis*) have all gained a foothold in CACO's wetlands, and numerous other introduced aquatic and wetland species may also be displacing native species and altering wetland communities throughout the park. The widespread potential for a severe impact to native marine and freshwater systems on the outer Cape creates a critical need for the documentation of invasive aquatic species occurrence and density at CACO, to be followed by control efforts and long-term monitoring.

Research Needs.

A baseline inventory of CACO's non-native plant species, including invasive wetland flora, was completed in 2001; a similar study is still needed for invasive aquatic fauna. Long-term monitoring and a CACO-specific invasive species management plan are also needed to mitigate the impact of introduced aquatic plants and animals on native species within the park.

Kettle Ponds.

Background.

The twenty kettle ponds within Cape Cod National Seashore are a unique and sensitive resource

with significant ecological, aesthetic and recreational value. Formed by ice blocks left behind during the last glacial retreat and filled with freshwater as a result of precipitation and sea level rise, these kettle ponds are surface exposures of Cape Cod's water table. They are also home to an unusual assemblage of plants and animals. Kettle ponds support myriad and diverse aquatic fauna from leeches to dragonflies, including many state listed rare species, and the kettle pond environment is the preeminent rare plant habitat in the park. In 1990, LeBlond identified eight state listed plant species at eighteen sites within CACO kettle pond habitats. Largely oligo- or mesotrophic and naturally acidic (Soukup, 1977), the ponds are extremely clear and biologically unproductive, and are highly susceptible to changes in water quality caused by increased sedimentation and nutrient loading.

After the ocean and bay beaches, the freshwater kettle ponds are likely the most visited natural area within the seashore. Fishing, boating, swimming and picnicking are popular activities at many of the ponds. In addition, there are year-round and seasonal houses on some of the pond shorelines. All of these adjacent dwellings rely on septic systems, which, given the porous nature of the groundwater aquifer, may contribute to pond eutrophication. Increasing numbers of seasonal cottages are being converted to year-round residences, with a resulting year-round impact, not only from septic effluent, but also from gardening herbicides, fertilizers and eroded soils. Land ownership of the ponds and adjacent shorelines varies between the National Park Service, the state of Massachusetts, individual towns and private citizens. Given the intensity of the recreation in, on and around the ponds, the varying ownership patterns and multiple jurisdictions surrounding them and their inherent biological fragility, managing kettle ponds to protect water quality and adjacent freshwater habitats has become one of the most complicated and important management programs at CACO.

With concerns for apparent eutrophication caused by human-induced nutrient loading, an intensive annual water quality monitoring program has been ongoing at CACO's kettle ponds for the last nine years. Bi-weekly measurements profiling pH, temperature, conductivity, water transparency and dissolved oxygen are now determined during the summer months at fifteen of the twenty kettle ponds within CACO. In addition, chlorophyll α and nutrients are monitored semi-annually (April and August), and pH and alkalinity have been determined quarterly at nearly all park freshwater bodies since 1984. This monitoring program has become institutionalized at CACO and is being conducted by seasonal resource management biological technicians.

Kettle Ponds, continued.

Research Needs.

Aquatic Ecology

Review and Evaluate Existing Water Quality Data: Water issues on the outer Cape, and kettle ponds in particular, have been the focus of considerable high quality research in recent years. Despite this extensive research effort, a consistent, quality-defined synthesis describing past and present pond conditions, trends, and projections for the future is still needed for a complete understanding of the issues surrounding kettle pond management at CACO. This work is expected to build upon that of the Kettle Pond Data Atlas (Portnoy et al., 2001) and should include recommendations for future study.

Evaluate Feasibility of Remote Multi-Parameter Data Logging: Remote sensing of aquatic environments has become a reality for many types of key water quality data, lessening the need for staff to frequently monitor a number of easily measured parameters. Coupling such multi-probe devices with cellular phone uplinks can also provide real-time information, which can be used to alert resource managers to unusual events in the ecosystem and to increase public awareness of pond conditions. A review of available multi-parameter probes, logging and real-time systems, including prioritized CACO data needs and information dissemination possibilities and a cost-effectiveness evaluation, is needed in order to evaluate the feasibility of implementing this new technology at CACO.

Monitor Pond Phytoplankton: Specific phytoplankton associations can be used as indicators of a pond's acidity and nutrient levels, and may provide early warnings of changing environmental conditions. Due to their short generation times and quick, detectable responses to environmental change, pond algae populations can express environmental fluctuations in just a season or two, where other means of observation might allow the same changes to remain unnoticed for years. Regular monitoring of phytoplankton species composition and abundance in CACO kettle ponds would thus be a valuable supplement to CACO's well-established water quality monitoring program.

Monitor Kettle Pond Margin and Wetland Transition Macrophytes: Given the inherently low nutrient levels at these ponds, impacts from septic effluents on pond water quality and associated flora and fauna are of real concern. A baseline survey of pond margin and wetland transition macrophytes, including maps of current macrophyte distribution along pond shorelines and inventories of the species composition and abundance of emergent vegetation at each pond, has recently been completed (Roman et al., 2001). Long-term monitoring is now necessary to assess and detect changes over time in pond margin species composition and distribution. Established transects should be revisited every 5-10 years in order to monitor such vegetation change relative to water chemistry, adjacent land use, atmospheric deposition and climate change.

Kettle Ponds, continued.

Inventory Aquatic Macrophytes: In addition to increasing pond margin and wetland transition macrophytes, increased nutrient loading from septic systems and other sources can also greatly increase aquatic macrophyte production. While good historical information exists on the presence of pond shoreline plants (Soukup, 1977; Hinds and Hathaway, 1968), there is limited quantitative data on the abundance of these species. So far, baseline inventories have only been completed for five of the twenty ponds. The remaining fifteen ponds need to be inventoried for existing emergent vegetation according to techniques currently used by the Massachusetts Department of Environmental Protection and by the Massachusetts Water Watch Partnership, and adapted from the United States Environmental Protection Agency. Once these baseline surveys have been completed, a long-term monitoring program must be designed and implemented in order to detect and evaluate any changes in plant species abundance and composition.

Evaluate the Role of Aquatic Macrophytes in Nutrient Sequestering: New research suggests that the aquatic macrophytes which occupy the shorelines and shallow waters of CACO kettle ponds may be vital to maintaining pond clarity. Like the growth of algae, the growth of aquatic macrophytes in Cape kettle ponds is largely dependent on the supply of phosphorous, an element that is scarce in native Cape soils but one that is introduced in significant quantities by human development and recreational activities. In deep kettle ponds where rooted plants are limited to the shorelines, excess phosphorous mostly benefits planktonic algae, which cloud the water and strip it of oxygen during their decomposition process, creating the potential for massive fish kills. Not only do aquatic plants compete with these algae for phosphorous in the water column, but new research suggests that they may also reduce eutrophication by producing conditions in pond sediments that lead to permanent phosphorous sequestration. In the presence of oxygen brought by these plants into their root zones, soluble ferrous iron is oxidized to form nonsoluble ferric oxyhydroxide, which absorbs phosphate. The phosphorous is thereby removed from the groundwater before it reaches the open pond environment. In the same way, phosphorous that leaks from decomposing organic matter along the pond's shorelines may be "captured" in the plant's aerated root zones and kept out of pond water, to the detriment of algae and benefit of pond clarity and overall pond health. Preliminary analysis of sediments in vegetated versus non-vegetated areas indicates that phosphorus is more abundant in the sediments of vegetated areas (Portnoy, unpublished data, 1997). However, many questions still remain: Do the macrophytes scavenge phosphorous from the water column and sequester it in the aerobic zone? Do they provide the chemical environment necessary for converting phosphorous pollutants in groundwater to a nonsoluble form before they can become part of the plant or algal biomass? Is the phosphorous permanently sequestered or only temporarily sequestered for later release? Further evaluation of the phosphorous sequestration process is necessary, and will require analysis of the phosphorous partitions and redox potential in the sediments of both vegetated and non-vegetated areas. Samples should be collected over several seasons to determine the permanence of the sequestration effect.

Kettle Ponds, continued.

Develop Nutrient Budgets and a Nutrient Loading Risk Assessment for Each Pond: Understanding the causes of kettle pond eutrophication involves understanding the dynamics of nutrient supply, pond response and loss of pond nutrients. Partitioning the sources of nutrient input into ponds, particularly during critical periods of biological activity, is thus necessary in order for resource managers to make informed decisions about water quality maintenance and restoration. Such nutrient budgets need to be developed for all twenty kettle ponds within the seashore, according to the priority order established by Martin et al. in 1993. Since the nutrient inputs and outputs at CACO kettle ponds are primarily groundwater with potentially significant inputs from the atmosphere (including temporary avian visitors), the task of developing such nutrient budgets at CACO requires a close coupling of hydrogeological and limnological techniques. Although well-developed nutrient loading models exist for surface water input and output systems, no models are currently in place for groundwater-dominated systems and so initial research will require direct measurement of pond inputs. Such measurement will require a shoreline ring of multi-level piezometers to intercept groundwater from the watershed (The same well network is required for the study of septic system impacts currently being initiated by the USGS –see below—, and thus may be coupled with the USGS research.) The National Atmospheric Deposition Program site may be used for additional nutrient measurements, and work done by Portnoy on avian contributions (1990) along with waterfowl counts may be used to estimate transient contributions. Inlets and outlets should be sampled with grab sample methods at monthly intervals and after significant precipitation events, and in-lake monitoring should follow the protocols described in Martin et al. (1993). As the database develops, correlational models between land use and hydrogeological characteristics should be developed with the hope that later nutrient budgets can be related to these models rather than to the more costly direct measurement techniques. Upon completion of these nutrient budgets and of the septic system leachate research described below, the impact of individual septic systems should be determined, and an estimation of aquifer water quality based on area-wide sources of pollution should be developed. A sensitivity analysis should also be conducted to determine the impact of potential changes in CACO practices on aquifer and kettle pond water quality.

Monitor Septic Leachates: Nutrient loading from failing septic systems or cesspools of adjacent pondshore cottages and homes is, as mentioned above, a major management concern. At present, potential impacts from these systems are not linked to their sources. An investigation of nutrient transport along shoreline flow paths from septic leach fields is underway at Gull Pond (Coleman et al., 2000). However, a long-term monitoring program for all ponds is still needed in order for CACO staff to define point sources of septic effluent and evaluate the effectiveness of future modifications or upgrading of private and NPS septic disposal systems. Additionally, the rate of nitrate and phosphorous attenuation relative to the distance of septic systems from pond shorelines needs to be determined. Replicate residences should be selected for both year-round and seasonal impacts, and with septic systems far enough from a pond to permit accurate evaluation. Sampling of shallow wells with 1 to 5-foot screened intervals

Kettle Ponds, continued.

should be conducted monthly for one year to evaluate seasonal affects on the rate of nutrient attenuation.

Characterize Pond Hydrogeology: Hydrologic characterization of Gull and Duck ponds (Horsley & Witten, 1996, Sobczak et al., in review) has done much to explain their very different water chemistries. Indeed, as surrounding land use changes, the influence of local hydrology on all the kettle ponds is becoming even more important. CACO has installed siphon wells at nine ponds as part of the Seashore's Inventory and Monitoring Program (McCobb et al., 1999), but local bench marks and staff gauges are still needed at the remaining eleven. Additionally, the USGS has initiated research on an integrated groundwater model for the entire outer Cape (Masterson and Barlow, 2000). This study will delineate groundwater flow paths so that contributing areas can be mapped upgradient of each pond basin. Once available, this information should be combined with land use data and coupled to empirical and geochemical modeling results of the nutrient transport study (Colman et al., 2000) to estimate the influx of nutrients and other solutes to each pond via groundwater flow.

Research Post-Glacial Pond Development: Investigations into the paleoecology of CACO kettle ponds have been initiated as an effort to understand how modern environmental problems such as acid rain, toxic atmospheric deposition, cultural eutrophication and pollution of ground and surface waters have degraded these freshwater systems. To know how CACO ponds have responded to local and regional environmental impacts, it is necessary to compare recent changes in the ponds with past (that is, pre-European settlement) changes. In the absence of historical records, only paleoecological study of lake sediment cores can provide this long-term perspective. Several paleoecology studies have been already been completed at CACO (Winkler 1982, 1985, 1988, 1989, 1994 and 1996, and Winkler and Sanford, 1995), and complete sediment cores have been taken at ten of the twenty kettle ponds. Research is still required, however, to determine the origin and basal ages of the remaining ponds. In addition to its role in defining the post-glacial landscape and time frame within which the kettle ponds developed, such research is expected to help explain the interruption of pond sediments by massive sand and gravel deposition in the early- to mid-Holocene era, and also to increase the overall understanding of topography on the outer Cape since de-glaciation, the building of barrier beaches, bays and salt marshes, and the effects of these physiographic changes on the development of the kettle ponds and on the changes in the flow of water across the narrow outer Cape peninsula.

Research Changing Diatom Assemblages: Specific diatom assemblages can be used as indicators of a number of a pond's contemporary water quality parameters (pH, salinity, water level, etc.), and diatoms found in pond sediment can reveal the same characteristics about a pond's past. The species composition of these water-quality-sensitive assemblages has changed, however, since the time of European settlement. Diatoms indicating acid conditions before settlement are different from those that indicate acid conditions now and, similarly, diatoms indicating nutrient increases today are different from those species that indicated similar trophic changes in the past.

Kettle Ponds, continued.

Further study of this species replacement is required in order to fully understand the circumstances surrounding these relatively recent biological changes in CACO kettle ponds.

Survey Invasive Species and Develop an Emergency Response Plan: Throughout Massachusetts, severe lake and pond problems are resulting from the introduction of invasive, introduced species of aquatic macrophytes. While many of the invasive species common to Massachusetts wetlands prefer nutrient-rich, relatively hard water and higher pH than what is typically found at CACO kettle ponds, others are broadly tolerant. Within a few years, an accidental introduction can spread throughout an entire pond, severely impacting both water quality and native plant and animal species. In order to detect the presence of these potentially harmful plants before serious damage occurs, a yearly qualitative survey for initial colonization of any species identified by Mattson et al. (1997) as serious potential threats to Massachusetts lakes and ponds is necessary. An emergency response plan should also be developed for use in the event that an invasion is detected, as eradication is far easier initially than in later years when whole pond chemical treatment, a technique inconsistent with National Seashore policy because of its effects on native species as well as the targeted invasives, may be the only alternative.

Inventory Benthic Invertebrates: No information currently exists on kettle pond benthic invertebrates in Cape Cod National Seashore. A complete baseline survey of benthic invertebrates in each pond, followed by the design and implementation of a long-term monitoring program, is necessary in order to evaluate the effects of the state's active fishery enhancement program (stocking and pond liming). In addition, metals concentrations in invertebrates are useful indicators of water quality changes, especially acid balance (which is of particular concern given the well-documented history of acid deposition on Cape Cod.) Baseline data on benthic invertebrates is thus also critically needed in order to understand the impacts of water quality changes on the outer Cape. Initial investigations should focus on ponds selected to represent a full range of water chemistries, depths, sediment types and plant communities, and eventually expand to include all twenty kettle ponds within CACO boundaries. Functional models of faunal/habitat relationships need to be developed and verified, and detailed protocols for characterizing benthic invertebrate abundance and diversity, along with important environmental attributes, should also be produced.

Research the Zooplankton Community in Duck Pond: Summer zooplankton hauls at Duck Pond, a 5.1-hectare, 18-meter-deep kettle located at the top of the Chequesset groundwater lens in South Wellfleet, typically yield only one or two copepod species (MacCoy 1958), yet the sediment record shows that *Neobosmina tubicen, Diaphanosoma* sp. and at least fifteen littoral cladocera species exist in the pond. Research is needed to explain this apparent discrepancy.

Kettle Ponds, continued.

Investigate the Causes of pH Changes in Ryder Pond: The pH of Ryder Pond, an 8.3-hectare, 11-meter-deep kettle pond located in the Wellfleet outwash plain, declined dramatically from 5.8 to 4.3 between 1983 and 1992, increased slowly to 4.6 by 1999, and then rapidly recovered to pH 5.4 by April 2000. None of the many adjacent ponds of similar morphometry and geologic setting exhibited a similar change in pH and, more regionally, the median pH of ponds across Massachusetts increased steadily over that same period (Godfrey et al., 1996). Local hydrology, as well as biogeochemistry, may play a major role in these observed water quality changes, and may explain why Ryder behaves so differently than nearby, otherwise similar kettle ponds. Pond water sulfate, monitored since 1985, seems to vary directly with acidity, increasing from an original 7 mg/L to a maximum of 14 mg/L by 1993, and declining along with acidity thereafter. Ryder Pond also experienced a significant and systematic decrease in mean summer transparency (the result of increased algae production) beginning in 1993. High sulfate has been associated with increased lake production through competition between sulfide and phosphate for iron precipitation or sorption sites (Caraco et al. 1989, 1990). Atmospheric deposition, measured at the local NADP site, is too small, however, to explain the increase in pond water sulfate even if the anion had accumulated conservatively. Pond water chloride varied little (30-33 mg/L) over this period so that sea salt inputs, whether transported as salt spray or in precipitation, were also not an important factor. Thus, the sulfate responsible for the acidification of Ryder Pond must have been mobilized from within the watershed. Research is required to understand the sulfur cycling and sulfate mobilization responsible for such profound changes in the acid balance of Ryder Pond over the past 15 years. The cycling of other elements, especially phosphorus and iron, should also be investigated as likely participants in observed changes in water chemistry and productivity since 1984.

Develop Individual Management Plans for Each Pond: Each of the twenty kettle ponds within CACO has different physical and ecological characteristics, public recreation uses and land ownership patterns. In order to meet the specific needs of these diverse resources, efforts are underway to develop management plans for each of these ponds. These plans will establish the purpose and needs, program direction, responsibilities and scheduled activities necessary to accomplish stated recreation and conservation goals at each pond. Management plans for three kettle ponds completely within NPS jurisdiction (Snow, Round West and Spectacle) have been completed. Development of plans for two other ponds with multiple ownership (Duck and Gull) was started but never finished. Management plans need to be completed for these two ponds, as well as the remaining fifteen. Plans should be developed with the assistance of park staff and, when appropriate, an ad hoc public advisory group.

Develop a Comprehensive Kettle Pond Management Plan: Once individual plans have been completed for at least half of the CACO ponds, work should begin on a comprehensive kettle pond management plan that consolidates common elements from the individual plans while also providing flexibility for their differences. As with the pond-specific plans, the principal goals of the integrated management plan are to

Kettle Ponds, continued.

minimize impact, mitigate problems, preserve sensitive ecosystems, maintain water quality and landscape aesthetics and provide sustainable recreational opportunities for both local landowners and day visitors. Since the solution of many of these issues requires the sustained participation of pond users, they should be incorporated into the planning process at an early stage through public meetings and the use of public advisory groups, as established during the development of the individual pond plans. A technical interagency committee consisting of local, park, state and academic members who are knowledgeable about CACO ponds, the local environment and watershed management should also be established to assist in reviewing existing knowledge about the ponds, recommending a common process for involving the larger community, identifying and prioritizing problems, and evaluating existing and designing new monitoring and management programs.

Inventory Human Impacts: With the high volume of public pond use during the summer, some environmental impact to the adjacent shoreline is inevitable. Unfortunately, relatively little quantitative information presently exists on the condition of pond trails and beaches. These areas, if severely eroded, could be contributing to a deterioration in pond water quality. Most trails have not been catalogued and erosion associated with trail and shoreline use is not known. In addition, some CACO areas appear to be annually enlarging. In many areas, trampling and subsequent loss of ground vegetation, shrubs and tree seedlings continue to be unquantified. A standardized monitoring protocol is currently being developed to provide for the detection and evaluation of human impacts to pond shorelines and adjacent slopes. Upon its completion, long-term monitoring data needs to be collected to provide an objective record of site conditions over time and to allow for an evaluation of impacts. With an active monitoring system in place, pond shore deterioration could be detected and appropriate management actions implemented before severe or irreversible impacts (especially to water quality) occurred. In addition, monitoring use patterns and impacts would provide a mechanism for developing management strategies and for evaluating the success or failure of resource protection measures following their implementation.

Develop Revegetation Plans: Intense and concentrated public use has caused significant bank erosion at a number of kettle ponds. These areas are now devoid of vegetation and sediment from the bank has eroded into the ponds, burying adjacent submerged and emergent vegetation. A recent three-year project resulted in the stabilization and revegetation of some pond shorelines. However, revegetation was only partially successful and many other shorelines require planting and protection. Each impacted area needs to be surveyed, and detailed site maps developed. Using these maps, specific work plans must be generated to re-contour and/or fill eroded slopes, rehabilitate trails, erect fencing and revegetate bare soil. Once revegetation efforts have been completed, follow-up monitoring of the newly established plants will be necessary to evaluate the success or failure of the efforts and to identify any areas that require additional attention.

Kettle Ponds, continued.

Study Public Use: Given the intensity of recreation and potential impacts of CACO visitors, a vital component of any future pond management program must focus on people. Currently, we have no information available about pond users, including how many people visit the ponds, recreational uses of the ponds and pondshores, and public attitudes and expectations about pond management issues. Baseline data about recreation use patterns and people's attitudes are critically needed to provide an objective record of current conditions and to help in directing future management actions aimed at protecting resources. This information would also enable the park to adequately evaluate the success or failure of these actions following their implementation. Specific data needs include:

1. Visitor Use Patterns: an estimation of the numbers of visitors at each pond by specified times of the day and the relative abundance of visitors engaging in various recreational activities;
2. Public Attitudes: Who are pond visitors? What is their knowledge about the sensitivities of the ponds? What are their attitudes about various management alternatives? Why do they visit the ponds and what are they expecting from their visit? What is the quality of their site visit? What are their perceptions of crowding?

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Landfill Impacts on Groundwater.

Background.

Municipal landfills in the towns of Wellfleet, Truro and Provincetown are currently unlined and, with the exception of Provincetown, uncapped solid waste and septage disposal sites within or adjacent to the boundaries of Cape Cod National Seashore. All three introduce leachate high in nitrogen, metals, volatile organic compounds (VOCs) and oxygen demand into the local aquifer, which is the sole source of potable water and the hydrologic source for all freshwater-dependent natural resources on the Outer Cape. These leachate plumes travel with groundwater flow, eventually discharging into surface water resources in and adjacent to CACO. Although actual discharge locations and effects are uncertain, it is likely that the Wellfleet landfill leachate plume flows into the Herring River, that Truro leachate impinges the Pamet River and that the Provincetown plume reaches both nearby ponds and Provincetown Harbor. Potential effects include pond and coastal water eutrophication, oxygen depletion, and metals and VOC toxicity to aquatic biota.

Research Needs.

Evaluate Past Study Design: Prior landfill monitoring efforts in the CACO vicinity need to be studied and evaluated for effectiveness, and a long-term program for improving the monitoring network and techniques needs to be developed. Specific attention should be paid to the scope of previous chemical analyses and to the depths and placement of existing observation wells.

Continue Plume Monitoring: Soil boring has been conducted and monitoring wells established at all three landfills, as well as two in Eastham and Orleans which also have the potential to impact water resources within the seashore, and the contamination plume at each site has been mapped. Additionally, models of the outer Cape groundwater system are currently being developed by the USGS-Water Resources Division (USGS-WRD); when completed, these models should prove useful for tracking plumes throughout the aquifer. Further research at the level of the Provincetown leachate plume study (Urish et al, 1993) is required to define the chemical nature and discharge location(s) of the landfill and septic leachate plumes at the other four sites. Initially, the resolution of water table mapping should be refined to enable more accurate predictions of flow direction and velocity. Electromagnetic soundings should be conducted to suggest leachate depth and flow paths. These data will allow the strategic placement of additional observation wells and soil borings for sampling and monitoring contaminated groundwater quality, both during the study phase and for resource monitoring indefinitely into the future. If, as in the case of Provincetown, leachate is found to enter surface waters, additional impact assessment will need to be conducted with an emphasis on geochemical changes to contaminants and the biological effects of nutrient loading.

In addition to more detailed individual studies for each landfill, a synchronized study of all five sites is necessary to fully evaluate the effects of landfill leachate on outer Cape

Landfill Impacts on Groundwater, continued.

groundwater. In consultation with the Massachusetts Department of Environmental Protection and the USGS – WRD, existing monitoring and observation wells around all five landfills should be revisited, and measurements of specific conductance and pH taken, along with hydrostatic head determinations. Samples should be collected from each well and analyzed for major indicators of contamination, including chloride, alkalinity, sodium, nitrate and dissolved organic carbon. These data should then be entered into CACO's Geographic Information System and contour maps generated to provide a synoptic picture of the landfill plumes impacting the seashore. This synchronized survey should be done annually for three years in order to gauge changes in the plumes.

Literature Review of Capping Methods: Existing landfills in or near CACO clearly need to be capped in order to minimize the creation and migration of toxic leachate into ground and surface waters. A literature review of available landfill closing techniques needs to be undertaken, with particular attention paid to the influence of various methods on the migration of existing contaminant plumes and on further leachate generation. Based on hydrological assumptions about the effects of the capping techniques, numerical modeling of the plumes should be completed and likely scenarios predicted.

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Larvicide Impacts on Native Invertebrates.

Background.

Despite the absence of a public health threat, wetlands on outer Cape Cod have been altered to control dipteran insects for over 300 years. In the nineteenth and twentieth centuries, large areas of the tidal wetlands now included within Cape Cod National Seashore were diked and grid-ditched to reduce breeding habitat for salt marsh populations of nuisance mosquitoes. Since 1938, the state program of nuisance insect management has been conducted by the Cape Cod Mosquito Control Project (CCMCP).

When the seashore was established in the early 1960s, the deeds of conveyance for the Province Lands and Pilgrim State Park included a provision allowing the CCMCP to continue certain activities for the "proper control" of mosquitoes and greenhead flies. Although the CCMCP has no specific authority to conduct nuisance insect control elsewhere in the seashore, ditch maintenance, larvicide treatments and, in the case of Pilgrim Lake, water level control continue throughout CACO wetlands. National Park Service policy normally does not permit native insect control in the absence of a public health emergency. (The regionally important arbovirus eastern equine encephalitis is not a problem on Cape Cod.) The effects of ditch drainage on coastal wetland ecology have been studied (Soukup and Portnoy, 1986; Portnoy, 1999; Roman et al., 1995), and are expected to be mitigated by ongoing salt marsh restoration. Larvicide treatments may have long-term effects on native invertebrates (including mosquitoes) and dependent fauna (Hershey et al., 1998). Researching the impact of mosquito larvicide treatments on native invertebrates will enable both CACO and the CCMCP to make more informed decisions regarding the management of some of CACO's most productive wetland systems.

Research Needs.

Research on the impacts of mosquito larvicide treatments on native invertebrates within Cape Cod National Seashore, as well as an assessment of the efficacy of these treatments on the target organisms, is needed.

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Larvicide Impacts on Native Invertebrates, continued.

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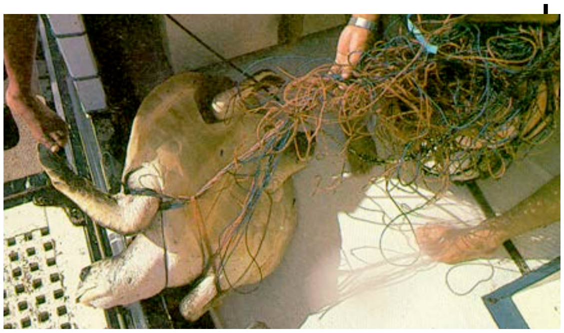
Marine Debris.

Background.

The amount of debris found on beaches and at sea in recent years is a national, indeed global, ecological concern. Debris that is washed ashore not only diminishes the scenic value of beaches, but while adrift at sea it can also be lethal to marine wildlife. Of particular concern is plastic, which accounted for nearly 89 percent of all marine debris found on Cape Cod beaches in a 1990 survey (Manski, 1991). The National Wildlife Federation estimates that over one million birds and 100,000 marine mammals worldwide die each year as a result of ingesting or becoming entangled in floating plastic debris (Van Dusen, 1988). Typically, birds die after consuming various small plastic particles, mistaking them for a normal meal of crustaceans or fish eggs, and turtles often mistake plastic bags and balloons for jellyfish, a prime food source. The indigestible plastic blocks the animal's intestines, causing ulcers and eventually starvation. Marine mammals such as seals and whales are also at high risk for entanglement in fishing gear and other plastic debris. Unable to move or feed normally, the entangled animals die from drowning, exhaustion and even starvation.



Some of the human-generated debris washing ashore on CACO beaches also present hazards to visitors and employees. Bottles, boards with protruding nails, light bulbs and other sharp objects, and discarded fishing nets and traps are among the many hazardous items routinely recovered from beaches.

Prior to 1988, data on the types and distribution of debris washing up at CACO and other coastal areas were generated primarily from voluntary beach clean-ups. While these data are useful for public education and media purposes, they are inadequate for quantitative assessment of the problem, developing solution strategies and evaluating the effectiveness of recent legislation that prohibits ocean dumping of plastics.

In an effort to establish a national database on the marine debris problem, the National Marine Fisheries Service (NMFS) entered into a five-year cooperative research program with the National Park Service in 1988. This venture established systematic surveys in each region of the coastal United States to assess the types, quantities and sources of human-generated debris washing ashore. CACO was one of eight NPS units participating in this national monitoring program.

Marine Debris, continued.

Research Needs.

As part of the NMFS study, marine debris found along five 1-km sections of accessible shoreline (two bay and three ocean beaches) was monitored quarterly (Manski 1990, 1991). All human-generated debris observed along these permanent survey transects was recorded and either removed or marked. Procedures followed those established by the NMFS and the Washington Support Office for the Division of Wildlife and Vegetation. This monitoring effort, which was last undertaken almost a decade ago, needs to be resumed and continued on a long-term basis in order to track changes in marine debris composition and abundance and to evaluate the effectiveness of preventative legislative measures.

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Mercury Contamination of Aquatic Environs.

Background.

Results from a joint research project conducted by the Maine Departments of Environmental Protection and Inland Fisheries and Wildlife and the University of Maine to determine the distribution and magnitude of chemical contamination of fish populations in 120 Maine lakes have revealed a high degree of mercury contamination in fish from Maine lakes, including two lakes in Acadia National Park (ACAD). Statewide, about half of the fish samples had mercury concentrations of 0.5 ppm (wet weight) or higher, and about twenty lakes contained at least one fish in the sample that exceeded 1 ppm mercury, the US Food and Drug Administration action level for mercury in fish tissue. The highest mercury levels of all fish in this study (3.4 and 2.8 ppm) were found in the two largest bass sampled. Such extremely elevated mercury levels are of concern both to human health and to the health of wildlife predators. Because mercury is the only known metal that bioconcentrates and biomagnifies in the food chain and thus has wholly harmful effects when present in fish and wildlife, the alarming levels found in Maine ecosystems with close parallels to the kettle ponds of Cape Cod National Seashore warrant a closer look at the seashore's own fish populations.

Prompted by the results of the Maine research, the United States Geological Survey --Biological Resources Division is currently monitoring mercury contamination in five CACO kettle ponds, as well as at ACAD. Yellow perch, a favorite with CACO fishermen, is known to accumulate significant amounts of mercury in its tissue and mercury contamination has indeed been found in yellow perch from all five of the CACO study ponds. Importantly, all perch examined in recent years at the three most acidic CACO ponds (Duck, Dyer and Great Ponds in Wellfleet) have exhibited gross necrotic lesions on the head and gill covers, a syndrome termed "hole in the head" disease. The etiology of this condition is poorly described in captivity and totally unknown in the wild; however, links may exist between pond chemistry, metals mobility and the disease.

Atmospheric deposition has been implicated as a major source of mercury in freshwater lakes worldwide. Mercury is of special concern at CACO because of the proximity and abundance of upwind sources, such as Boston-area hospitals and waste incineration plants. Many of the incinerators in Massachusetts are not properly equipped to filter mercury from air emissions; an estimated 19 tons of mercury are emitted by them every year. Additionally, fish mercury content seems to be highest in lakes with soft water (that is, low in dissolved ions and in acid-neutralizing capacity) and acidic pH, conditions that are common in both ACAD lakes and CACO ponds. It is also interesting to note that sulfate concentrations are very high (median 64 mg/L) in CACO kettle ponds, a condition that may promote mercury methylation and mobilization through reactions within sulfidic sediments.

Mercury Contamination of Aquatic Environs, continued.

Research Needs.

Monitor Mercury Deposition: The ability to understand the toxicity, bioaccumulation, chemistry and transport of such a ubiquitous contaminant requires a regional approach to monitoring, as established by the National Atmospheric Deposition/Mercury Deposition Network (NADP/MDN). An offshoot of the well-established NADP National Trends Network (NADP/NTN), which has a site in Truro, the goal of the MDN is to build a database of high-quality weekly mercury deposition observations from around the continent. Placement of an additional precipitation monitor, dedicated solely to monitoring mercury deposition, at the active NADP/NTN Truro site is planned for 2002. Wet deposition samples will need to be collected on a weekly basis and analyzed by a certified environmental laboratory for total mercury. After one year, cumulative data should be used to calculate atmospheric mercury loading rates on CACO ponds and long-term monitoring, according to the mercury monitoring protocol that is currently in development, should be initiated.

Monitor Top Predator Fish Tissue in Fresh and Estuarine Environments: In order to fully evaluate the threat mercury contamination poses to both human health and wildlife resources within the seashore, the program currently being conducted by the USGS-BRD needs to be expanded to include the remaining freshwater ponds and estuaries and to monitor for additional toxins. Findings of mercury contamination should be characterized according to species as well as pond distribution, and possible links between mercury mobility and “hole in the head” disease should be explored. In order to predict and potentially protect species at risk from mercury contamination, a food chain transfer of mercury must be demonstrated, and a historical data set of trends for mercury deposition in water and/or fish determined (see below). Finally, the implementation of a long-term mercury monitoring program is necessary to assess long-term changes in mercury deposition and uptake by aquatic organisms within CACO.

Evaluate Mercury Levels in Freshwater Pond Sediments: Surface sediment samples from different locations and depths in each of the twenty CACO kettle ponds are needed in order to fully assess the distribution of mercury in Cape aquatic environments. General sediment characteristics (grain size, organic content and bulk mineralogy) should be analyzed for each sample, and concentrations of mercury, as well as other toxic metals, sulfate and sulfide, should be determined by a certified environmental laboratory. Patterns in the distribution should be documented and contoured where appropriate. Once surface distribution has been determined for all twenty ponds, two ponds should be selected for sediment coring using a Livingstone corer or similar apparatus. These cores should be analyzed for vertical changes in sediment characteristics and toxic metal content in order to evaluate historical changes in mercury and other metal accumulation in the ponds. This analysis, combined with the fish tissue monitoring described above, will serve as the basis for a risk assessment to consumers of predator fish, including birds, humans and other mammals.

Mercury Contamination of Aquatic Environs, continued.

Evaluate Mercury Pathways: Based on the sediment and fish tissue data, one pond should be selected for intensive study of food chain pathways of metal bioaccumulation. Samples of lake water, surface sediments, benthic invertebrates, zooplankton and macrophytes, as well as forage and predator fish, should be analyzed for methyl mercury and total mercury content. Organisms should be stratified by habitat: pelagic, littoral, benthic (soft and hard bottom) and macrovegetation. Relatively high body burdens should be compared with habitat type to reveal possible pathways, which should then be confirmed by gut content analysis of larger species.

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Submerged Natural Resources.

Background.

Cape Cod National Seashore contains a wide variety of marine and freshwater resources,

including a heretofore largely overlooked community of submerged natural resources potentially as diverse and ecologically valuable as their well-studied aboveground counterparts. From highly productive eelgrass beds in sheltered estuaries to a complex marine network of flora and fauna in the open ocean off outer Cape shores, CACO's submerged resources are expansive and critical to the health of aquatic resources throughout the region. Massachusetts has designated all coastal waters surrounding the seashore as an ocean sanctuary (Mitchell and Soukup, 1980) and the seashore's boundary extends ¼ mile into nearshore coastal waters, yet its submerged natural resources have never been comprehensively inventoried. Given the potential for sea level rise accelerated by global climate change and the continued subsequent submergence of the CACO coastline, such baseline data on today's submerged resources are especially critical to our understanding of long-term ecological change in submerged systems.

Research Needs.

Convene Workshop: A workshop to address the present state of knowledge regarding submerged natural resources within the seashore is envisioned as the first step in a long-term effort to inventory and monitor CACO's underwater ecosystems. Building on the 1994 University of Rhode Island forum on CACO's submerged estuarine systems (Beatty et al., 1994), this workshop should expand in scope to include the park's purely marine and freshwater underwater communities. Participants in the workshop should include scientists, commercial and public users of submerged resources and representatives of the responsible management agencies. The forum should focus on reviewing available information sources and on identifying the presence of important species and habitats by ecological, regulatory and economic criteria. Preliminary evaluations of their location, controlling processes, seasonal changes and threats, both human and natural, should be made. Data collection methods should be addressed, including field and remotely sensed data, along with specific indicator species, habitats and processes on which to focus. Specific attention should also be given to the methodologies whereby any data, existing or yet to be gathered, can be incorporated into CACO's Geographic Information System.

Submerged Natural Resources, continued.

Design Monitoring Protocol: Following the workshop, a detailed protocol for inventorying CACO's submerged resources must be developed. Based on criteria established at the workshop and augmented by the investigator and CACO staff, the protocol should select and prioritize species and/or habitats to be studied, and identify data collection methods, seasonal modifications and indicators for each one. The protocol should further provide for investigation of submerged habitats with respect to physical structure, species composition, density (for select biotic groups), ecological quality and function. Threats to sensitive habitats and species also need to be identified and described.

Implement Monitoring: Upon completion of the protocol design, a prototype inventory of submerged resources should be conducted. Based on the plan, the actual inventory program should begin by focusing on a particular species and/or habitat type and gradually expand in breadth. The prototype inventory should include CACO staff as data collectors and logistical support in order to simplify the transition from prototype to institutionalized inventory. Continued monitoring according to these final inventory standards is then needed on a long-term basis.

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Wetland Plant Species.

Background.

Between 1984 and 1987, the distribution of rare plants in Cape Cod National Seashore (CACO) was mapped and, of all the habitats surveyed, pond shores emerged as the most threatened rare plant habitat in the seashore (LeBlond, 1990). Indeed, human pressures on all freshwater and saltwater wetlands in CACO may pose a substantial threat to wetland plant species occurring on or adjacent to wetland shores. Nutrient runoff from household septic systems and the resulting accelerated growth of aquatic plants is a critical concern. Municipal groundwater withdrawal plans and the subsequent lowering of the water table and changes in nutrient availability could alter the plant species composition of some CACO wetlands, thus allowing for increased encroachment of upland plants (Cortell, 1983, Roman et al., 1997). Foot traffic, flora and fauna collecting, shellfishing and other recreational uses of wetland areas also have an impact on wetland plant communities. While inventories have been completed that identify wetland plant species within CACO (Cortell, 1983; LeBlond, 1990; Patterson, 1988), quantitative monitoring to document the changes in species communities brought about by human impacts has only been implemented at five kettle ponds (Roman et al. 2001). Without field monitoring to document such changes in all of CACO's wetland plant species communities, CACO managers will lack quantitative data to support potential wetland protection measures.

Research Needs.

Map Inventory Data: Existing inventory and monitoring plots need to be identified, located and mapped on CACO's Geographic Information System.

Monitor Wetland Plant Communities: The wetland inventory and monitoring plots that currently exist within CACO use a variety of different classification and sampling systems. Development of a consistent re-sampling and monitoring protocol is planned for 2002; wetland areas without established monitoring plots or quantitative sampling data will be identified in priority order and consistent standards for classification and sampling of wetland plant species will be set. Once this monitoring methodology has been developed, long-term monitoring is necessary in order to track changes in wetland plant communities within the seashore.

Wetland Plant Species, continued.

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Atmospheric Monitoring

Air Quality.

Background.

Air pollution knows no bounds. Regional haze and light pollution obscure scenic vistas at nearly every national park and wilderness area, and in some areas, air pollution can even be a health concern. Because atmospheric conditions affect everything from groundwater to soil, from flora and fauna to human health, Cape Cod National Seashore actively monitors air quality on the outer Cape.

Unlike stratospheric ozone, which forms naturally in the upper atmosphere and protects the earth from harmful ultraviolet rays, ground-level ozone is formed through a series of chemical reactions between manmade emissions of volatile organic compounds (VOCs) and nitrous oxides (NOx) in the presence of heat and sunlight. Largely a result of fossil fuel combustion in motor vehicles and power plants, these compounds are taken up into the atmosphere in large quantities when the wind blows across heavily populated and/or industrialized areas. Airborne, VOCs and NOx become capable of traveling long distances. Thus, although relatively few of these ozone-forming pollutants are actually produced on Cape Cod, CACO is the recipient of a "pool" of pollutants that forms over the industrialized Midwest and heavily populated Northeast corridor. From 1996-8, CACO ranked 7th of all national parks in daily maximum ozone concentration, and the entire Cape is presently classified as a "non-attainment area" of the EPA's National Ambient Air Quality Standards (NAAQS) for ground-level ozone. Human exposure to ozone at levels above the 0.08 ppm NAAQS can aggravate asthma, reduce lung function and cause temporary eye and throat irritation, with repeated exposure leading to more serious chronic health problems, such as cancer and respiratory illness. At much lower concentrations, it can also compromise the growth, reproduction and overall health of many plant species. It is believed that the effects of ground-level ozone on long-lived species accumulate over time, with the potential for adverse impacts on entire ecosystems and ecological functions, including water movement and nutrient cycling.

A major contributor to acidic deposition in the eastern United States, sulfur dioxide is also a concern at CACO. The risk of surface water acidification is considered high in CACO's poorly buffered ponds and vernal pools, and sulfur dioxide may combine with ozone to cause a very severe needle tip burn in some of the park's conifer populations.

CACO is a Class II area under the Clean Air Act and has been monitoring precipitation chemistry through the National Atmospheric Deposition Program (NADP) and Massachusetts Acid Rain Monitoring Project since 1981, and ambient ozone through the Washington Support Office Air Quality Division and Massachusetts Department of Environmental Protection (DEP) since 1987. Investigations of both historic and current kettle pond chemistry have been conducted; however, levels of ambient sulfur dioxide on the outer Cape have not yet been determined.

Air Quality, continued.

Research Needs.

Conduct NADP Monitoring: The ability to understand the toxicity, chemistry and transport of ubiquitous air contaminants requires a regional approach to monitoring, as established by the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). The goal of the NADP/NTN, which has a site in Truro, is to build a database of high-quality weekly deposition observations from around the continent. Ambient air quality data is currently collected cooperatively by CACO and the Massachusetts DEP at the Truro site; continued monitoring is required in order to track long-term changes in air quality within the park and to evaluate the effectiveness of legislative measures addressed at improving air quality in the region.

Monitor Sulfur Dioxide: Sulfur dioxide monitoring needs to be undertaken at CACO's air quality monitoring site for at least three years in order to effectively determine the importance of sulfur dioxide as a contributory agent to acidic deposition within the seashore.

Monitor Fog and Marine Aerosol Deposition: Fog and marine aerosols may not only be an important source of moisture, but also of significant amounts of nitrate and sulfate. Investigations into the amount, rate and ecological effects of this deposition are needed.

Whenever possible, air quality inventory and monitoring efforts at CACO should be integrated into regional, national and global climate change programs.

(See related project description under "Mercury Contamination of Aquatic Environs" in the Aquatic Ecology chapter.)

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Coastal Geomorphology

Physical Oceanographic Processes.

Background.

Coastal wetlands and beaches in Cape Cod National Seashore are chronically polluted with waste from nearby urban and industrial centers, as well as from shipping lanes in the turbulent North Atlantic. Fairly small oil spills (less than 1000 liters) in the recent past at Coast Guard Beach and Hatches Harbor have clearly demonstrated the vulnerability of CACO resources, and the characteristics of beach litter, especially on bayside shores, have graphically illustrated CACO's sensitivity as a receptor for waste from metropolitan Boston. Regardless of the source or identity of the pollutants, their transport to outer Cape shores is dependent on the physics of the circulation of coastal waters, in turn controlled by short- and long-term geomorphology and local and regional weather. Seasonal changes in physical oceanographic processes likely also influence shoreline retreat and accretion, local fish populations and nutrient transport in the waters off Cape Cod, but CACO staff currently have no comprehensive source of information for physical oceanographic data affecting the outer Cape. Much of the data probably exists in different sources, and needs to be integrated into a coherent predictive tool to aid CACO managers in evaluating various on- and offshore developments and shipping proposals, and in forecasting the landfall of wastes for rapid and efficient cleanup and mitigation.

Research Needs.

Various sources of physical oceanographic data regarding transport to CACO waters and wetlands, and their relationship to shoreline change, local fish populations, nutrient input and contaminant movement in CACO waters, need to be investigated in order to better understand seasonal changes in physical oceanographic processes on Cape Cod. Existing data and models should be integrated into a system that provides CACO with the ability to pair season and approximate weather conditions to circulation patterns. If possible, such a program would be best incorporated into the evolving CACO Geographic Information System. Once developed, the predictive system would require regular updates to improve accuracy and technological precision and to accommodate observed changes in bathymetry and atmospheric forcing.

Related Research.

FitzGerald, D.M. and D.R. Levin. Hydraulics, morphology and sediment transport patterns at Pamet River Inlet: Truro, Massachusetts. Northeastern Geology. 1981; 3(3/4): 216-224.

Shoreline Retreat and Accretion.

Background.

Coastal erosion processes form the basis for a number of important natural and cultural resource management issues within Cape Cod National Seashore. Without erosion, the dunes and beaches so characteristic of Cape Cod would simply not exist; the Cape's wide beaches are borne of sand that erodes from the glacial cliffs along its shoreline, and just as some areas are retreating, others are growing with sand transported by wind and waves to their shores. All of the Province Lands, as well as Nauset Spit and much of Great Island, were created by the movement and relocation of sand as part of this process, and both Provincetown and Monomoy Island are still growing by about one acre a year with sand eroded from the outer Cape beaches. Although this dynamic process benefits coastal ecosystems, it can also complicate natural resource management in areas, like CACO, that are severely impacted by human activity. Shoreline configuration, shaped by erosion, determines the access routes and available corridor for public off-road vehicle (ORV) use in the seashore, and in the past has been responsible for re-routing ORV traffic closer to nests of the federally threatened piping plover (*Charadrius melodus*). Erosion can also cause severe damage to manmade structures that are built on top of the changing shoreline. The Highland and Nauset Lighthouses were recently moved inland to prevent them from falling into the sea, the Great Storm of 1978 completely demolished a 300-car parking lot located at Coast Guard Beach, and more recently, several private homes on a town-owned beach in Chatham were lost to the ocean as a result of shoreline retreat.

The areas that comprise the seashore have been continuously inhabited by European settlers since the mid-1600s, with historical impacts that include deforestation, nutrient-depleting agricultural practices, human-caused wildfire and sand mining. The migrating sand dunes in Provincetown are partly the result of human deforestation dating back to the seventeenth century, exacerbated in modern times by frequently used pedestrian social trails through the dunes. Although allowing natural shoreline processes to take place unimpeded is a primary management objective at CACO, justification for efforts to combat erosion in selected areas, primarily through planting beach grass (*Ammophila breviligulata*), is based on the premise that human activities initiated dune migration and continue to greatly accelerate the natural rate of erosion.

Shoreline Retreat and Accretion, continued.

Research Needs.

A geomorphic shoreline change monitoring program is currently being developed in partnership with the United States Geological Survey. Upon its completion, both immediate and long-term implementation of this plan will be needed to track and plan for geological changes to the outer Cape's coastline. Geomorphology monitoring plots established in the 1800s and 1970s should be identified and re-surveyed, when possible, to detect changes over time. Additional plots should also be established as needed, including areas on the Gut at Great Island in Wellfleet, and a sea level rise monitoring station should be set up to detect the long-term effects of global climate change on CACO's coastline. Once significant data have been acquired, CACO's Geographic Information System should be used to model future shoreline retreat, nearshore sand movement and dune migration. Although shoreline changes may be extrapolated from aerial photography, it is expected that the bulk of this research will be conducted through ground surveys, which are considered more effective.

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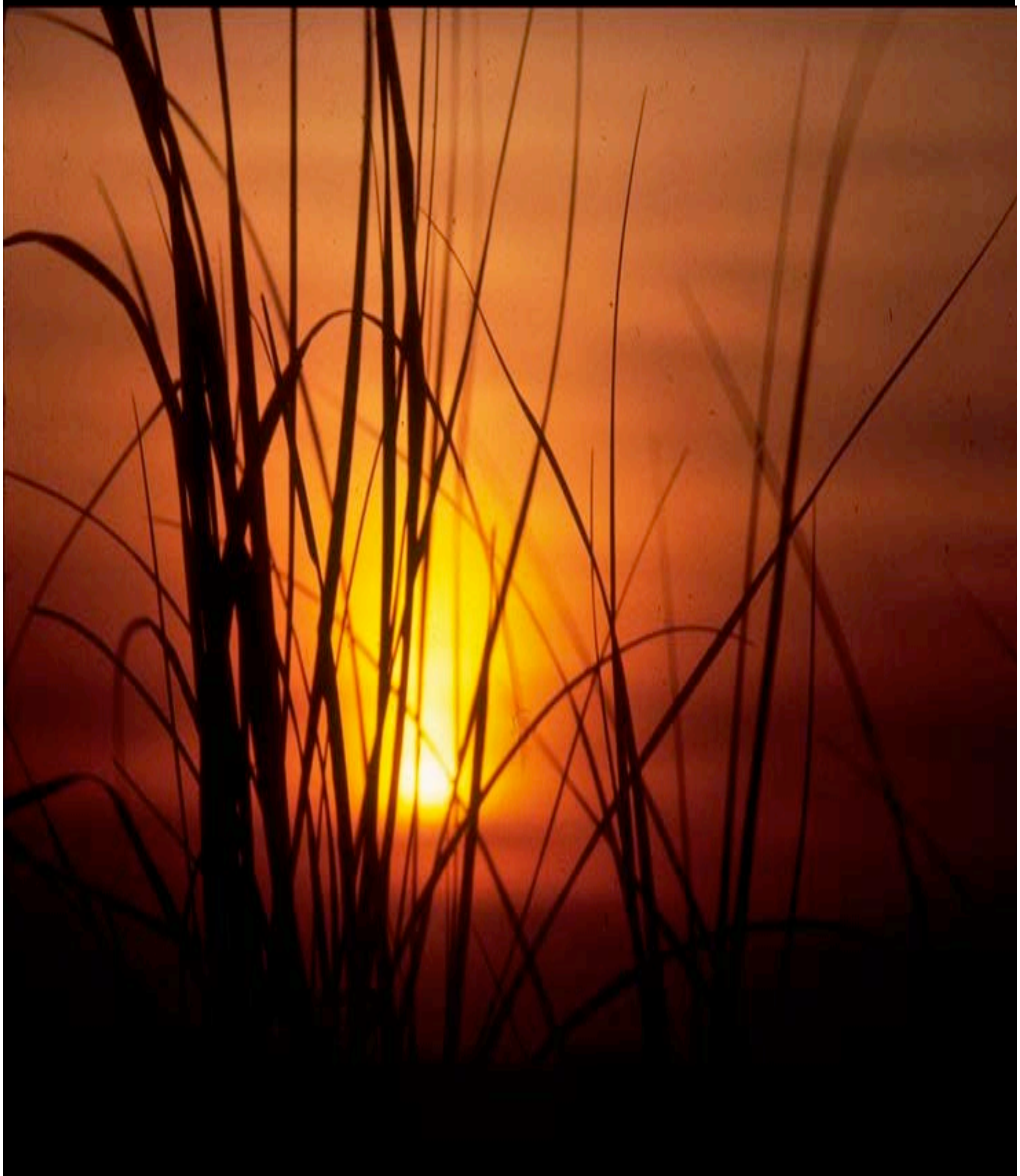
Plant Ecology



Heathlands.

Background.

The most extensive coastal heathlands in the United States today occur on Nantucket Island, Martha's Vineyard and on Cape Cod, primarily within Cape Cod National Seashore. One of CACO's most ecologically and culturally significant habitats, heathlands contain a diversity of species rivaled by few other plant communities in the region. Several heathland plants are endemic species found in no other habitats, and at least three state listed rare plants have been identified in CACO heathlands. Other species, though not considered rare due to their occurrence in the arctic-alpine flora, are not found close to sea level anywhere else in southern New England or New York.

Heathland plant species have been a component of Cape Cod's vegetation since the last ice age. They were the first to colonize the newly-formed Cape after the glacial retreat 15,000 years ago, followed by pine and oak trees, and eventually the hardwood forests first encountered by the Pilgrims. Early European settlers used this hardwood for building and fuel, and cleared the land for farming and livestock pastures. Without trees to shade out the smaller plants, the Cape once again became a haven for heathlands. In 1865, Henry David Thoreau recorded: *The old houses are built of the timber of the Cape; but instead of the forests in the midst of which they originally stood, barren heaths, with poverty grass for heather now stretch away on every side.*

These days, heathlands are rapidly disappearing worldwide. Development of heathlands for real estate plays a major role in their demise outside CACO boundaries. Within the protected lands of the Seashore, heathlands are also falling victim to natural processes, as forests overtake the heath in a repeat of the plant succession that occurred after the formation of the Cape. Since CACO's establishment in 1961, over 450 hectares of heathland have been lost to forest succession, representing a reduction of more than 64% over the last forty years. Moreover, the rate of heathland loss is apparently accelerating. Only nine major areas of heathland remain today in CACO; all have dramatically altered species composition, character and appearance since the seashore's establishment and all are threatened by forest encroachment (Carlson et al., 1991).

CACO's heathlands are some of the few areas worldwide where broom crowberry (*Corema conradii*), a species that has been considered for listing as federally endangered because of its globally restricted range, is actually abundant. Baseline information about crowberry-dominated heathlands in CACO, including life history, reproduction, recruitment and maintenance requirements of the threatened species, is currently being investigated by the University of Rhode Island (URI). Monitoring plots established in 1988 are being re-surveyed, a long-term monitoring protocol is being developed and drafts of a crowberry management plan are expected by 2003.

Heathlands, continued.

Given their aesthetic appeal, ecological significance, global rarity and rapid disappearance, protection of heathlands at CACO is a critically important resource management program objective. While active management of heathlands is occurring elsewhere (e.g. Nantucket), methods to successfully maintain this community and its biological diversity in CACO have yet to be implemented.

Research Needs.

Continue Heathland Monitoring: In 1988, Carlson and Godfrey established and quantitatively surveyed twelve long-term monitoring plots in the three types of heathland found at CACO. URI researchers are currently re-surveying these plots and developing a long-term monitoring protocol for CACO's heathlands; continued long-term monitoring according to this protocol is necessary to our full understanding of heathland community dynamics in the seashore. Specific attention should be focused on determining why some heaths have overgrown more rapidly than others. This information will also be valuable in evaluating the results of experimental treatments aimed at maintaining selected heathland areas.

Test Management Techniques: Limited work has been conducted to test the four available management strategies (burning, mowing, hand clipping followed by herbicide treatment and grazing) for maintaining heathland communities. The use of individual treatments and in different combinations needs to be investigated for site-specific conditions at CACO. This project should select several different heathland sites dominated by broom crowberry and bearberry (*Arctostaphylos uva-ursi*) and implement small- to moderate-scale experiments investigating which management strategies (and during which seasons) provide the best protection for these communities.

Develop Management Plan: In order to ensure proper management and long-term protection of this rare habitat, a comprehensive plan for the management of heathland communities at CACO needs to be developed. The plan should review historic and cultural landscapes associated with heathlands and the historic ecology of CACO upland plant communities, as well as all existing information on rare and endangered plants and animals in CACO heathlands. Historic and current data and vegetation maps should be used to identify the former extent of heathlands at CACO and to evaluate rates of successional change at different sites. Based on this analysis and on the appropriateness and ease of management for each site, the plan should identify areas of heathland to be managed, and outline a preliminary action plan for beginning management activities.

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Landscape Revegetation.

Background.

Cape Cod National Seashore has been continuously inhabited by European settlers since the mid-1600s, with historical impacts that include deforestation, soil nutrient-depleting agricultural practices, human-caused wildfire and sand mining. The migrating sand dunes in Provincetown are partly the result of human deforestation dating back to the seventeenth century, exacerbated in modern times by frequently used pedestrian social trails through the dunes. Dune stabilization, primarily with plantings of beach grass (*Ammophila breviligulata*), has been attempted for many years and appears to be successful. However, beach grass is a primary successional species, and long term stabilization of dunes will require succession to woody plant species.

In addition to dune and beach erosion, eroded slopes at kettle ponds are a serious concern. The result of disturbed or destroyed vegetation and soil compaction due to heavy summertime use by anglers and bathers, pondshore erosion may be contributing to a deterioration in the water quality of the ponds.

Research Needs.

Evaluate Dune Planting Program: Historically, dune stabilization efforts have been conducted by various municipal and private organizations using both herbaceous and woody plantings. Over 900 acres of previously forested and currently barren dune area in Provincetown have been identified as in need of vegetation (Leatherman, 1981). CACO planting of open dunes for dune stabilization purposes began in 1985 and 110 acres have been planted with beach grass to date. Although allowing natural shoreline processes to take place unimpeded is a primary management objective at CACO, justification for these large-scale plantings was based on the premise that human deforestation of the land initiated dune migration. However, Winkler (1990) argues that the Little Ice Age with its corresponding cooler temperatures and drier winds may have been a contributing factor in dune advancement equal to or greater than human disturbance. A review of the dune planting program is necessary to determine:

1. if planting all remaining 800 acres is necessary;
2. if woody species can be introduced and survive; and
3. if human disturbance or climate change (or both) was the driving force that initiated dune migration.

Landscape Revegetation, continued.

Evaluate Vigor of Plants: Observations indicate that dune plantings of beach grass effectively arrest dune migration. However, the long-term endurance of beach grass and its corresponding ability to stem erosion is not known and, in fact, recent observations of extensive planted *Ammophila* culm mortality in locations receiving little or no net sand accumulation suggest that past strategies for revegetation should be reviewed. As a first step, a scientific and resource manager panel should be convened to review past plantings and research and to recommend future alternative actions including but not limited to fertilization, secondary plantings of woody species, inoculation with myccorhizae, further research on *Ammophila* ecology including parasites and diseases, and current surveys of planting success relative to original program directives. Based on recommendations from the panel, monitoring and research should be undertaken to determine if beach grass plantings survive after nutrient input from imported soil decreases with dune stabilization, and to evaluate the effectiveness and applicability of planting secondary successional species (e.g. oaks, pines and shrubs.)

Inventory and Monitor Trails and Impacted Visitor Use Areas: Trails created by pedestrian traffic off established walkways have created an indiscriminate and arbitrary network of paths to and from CACO facilities, roads and beaches. Although some such trails have been recently mapped by CACO staff, a systematic inventory of social trails has not been done since the late 1970s. In order to successfully confine pedestrian traffic to established trails and to revegetate impacted sites, a current inventory of all trails is needed. Collected data should be entered in the CACO Geographic Information System and, when possible, alternate routes should be identified. Until the extent of maintained and social trails and their use is evaluated, natural resource damage, including erosion, loss of sand and vegetation destroyed by soil compaction, will continue to accrue in high visitor use areas.

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Non-Native Plant Species.

Background.

Cape Cod National Seashore has been continuously inhabited by European settlers since the seventeenth century, leading, among other things, to the establishment of many non-native plant

species within CACO boundaries. Salt-spray rose (*Rosa rugosa*), common along both ocean and bayside beaches and often used for erosion control, is a potentially noxious species that may compete with native beach plum (*Prunus maritima*) for space, pollinators and fruit dispersers. Japanese knotweed (*Polygonum cuspidatum*), an introduced invasive weed resistant to eradication, occurs just outside CACO boundaries in Provincetown, but can and does quickly invade disturbed sites. Morrow's Honeysuckle (*Lonicera morrowii*) has colonized and likely displaced native grasses and heathland species in Truro. Oriental bittersweet (*Celastrus orbiculatus*), purple loosestrife (*Lycopodium sabinifolium*), Tree of Heaven (*Ailanthus altissima*), Norway Maple (*Acer platanoides*), multi-flora rose (*Rosa multiflora*) and numerous other introduced plants may also be displacing native species and altering plant communities throughout CACO.

Given the widespread potential impacts to native communities, documentation of non-native plant occurrence and density is critical. A baseline inventory of CACO's non-native plant species was completed in 2001; long-term monitoring and a plan for invasive plant management are now necessary in order to mitigate the impact of introduced plants on native species within the park.

Research Needs.

Based on the mapping and inventory completed in 2001, a comprehensive plan for the management of non-native plant species at CACO needs to be developed. The plan should assess the degree of threat to park resources posed by each species, as well as the feasibility of successful control. Also included should be area- and species-specific action plans with detailed management methodologies, to be used in determining control effort priorities. Once the plan has been implemented, continued monitoring will be necessary to track changes in both native and non-native populations, and to evaluate the success of management efforts.

Non-Vascular Plants.

Background.

Cape Cod National Seashore's ability to protect non-vascular plant species within its boundaries is severely hampered by a lack of baseline information about their abundance and distribution. Little or no inventory information exists for bryophytes, lichens, fungi or algae within the seashore. Due to their sensitivity to air quality and precipitation chemistry and given the high levels of ozone and other air pollutants recorded at CACO in recent years, lichen research is particularly critical for identifying species that may be extirpated with present impacts from diminished air quality. Mushroom research too takes on added importance at CACO, where the traditional harvesting of mushrooms continues every fall with unknown impacts to the seashore's fungi populations.

Research Needs.

Inventory Non-Vascular Species: A complete baseline inventory of fungi, mosses, lichens and algae within the seashore is needed. CACO-wide field surveys should be completed, and the density and frequency of non-vascular plant species in CACO should be mapped and measured. Voucher samples should be taken, and a computer database developed for long-term tracking of field data. Following this initial inventory, long-term monitoring is necessary in order to detect and track changes in CACO's non-vascular plant populations over time.

Assess Mushroom Harvest: Currently, little information exists regarding the species composition, distribution and density of fungi within CACO. During the annual fall harvest, most, if not all, edible mushrooms are removed in certain popular areas. The extent of this harvesting and its impact on local flora and fauna are unknown, as is the long-term effect of removing propagules from the local mushroom population. Once the above fungi inventory has been completed, an extended evaluation of the mushroom harvest is needed in order to protect this vital component of CACO's plant community.

State Listed Rare Plants.

Background.

According to the Massachusetts Endangered Species Act, a comprehensive law requiring stricter environmental review of listed species than the federal law of the same name, plant species facing

possible extinction in Massachusetts may be designated by the state as Endangered, Threatened or Of Special Concern. Each classification reflects the species' population size and stability, its global distribution and threats to the viability of its habitat: Endangered Species are reproductively viable native species in imminent danger of extinction; Threatened Species are reproductively viable native species that are rare or declining within the state and are likely to become endangered in the foreseeable future; and Species of Special Concern are those native species where a population decline could threaten the species if allowed to continue unchecked, as well as those that occur in such small numbers or with such a restricted distribution or specialized habitat that they could easily become threatened.

Cape Cod National Seashore contains a total of 33 plant species listed as Endangered, Threatened or Of Special Concern by the Massachusetts Natural Heritage Program. Four of these species have been recorded historically but have not been confirmed in recent years. Although CACO successfully protects its listed species from many anthropogenic impacts, natural and artificial threats such as fire, forest succession, atmospheric pollution and human recreation still influence rare plant species and communities within the seashore. Rare plants in CACO have been identified and their distribution has been mapped (LeBlond, 1990); however, only sporadic census data on species abundance and density exist, and the consequences of human and natural threats to the species remain largely unquantified.

Research Needs.

An existing monitoring plan to collect abundance and density data from CACO's rare plant sites at least every three years needs to be implemented in order to track long-term changes in the park's rare plant populations. Monitoring should include distribution and site mapping of both existing and new rare plant sites on CACO's Geographic Information System.

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Wildlife Ecology

The Browntail Moth.

Background.

The browntail moth (*Euproctis chrysorrhoea*), a European species, was accidentally introduced into the United States in the late 1890s; by 1913, the insect had spread to all of the New England states, as well as New Brunswick and Nova Scotia in eastern Canada. Since then, natural controls have led to a slow decrease in the moth's North American populations and significant browntail communities now only exist on a few islands in Casco Bay off the Maine coast and in Cape Cod National Seashore. The invasive moth causes an allergic reaction, similar to the itchy rash caused by poison ivy, in people who come into contact with adults, larvae, webs or just molted body hairs that are carried by the wind. In addition, the moth's preferred foods are beach plum (*Prunus maritima*), shadbush (*Amelanchier* sp.), oak (*Quercus* sp.) and salt spray rose (*Rosa rugosa*), species that comprise a large part of CACO's dune flora. Because these plants play an important role in stabilizing dune ecosystems and in supporting state listed rare *Lepidoptera* (at least 28 rare species have been collected in the CACO dunes (Mello, 1986)), browntail moth feeding habits pose a potential threat to this sensitive ecological community. Observations of feeding larvae indicate that some host plans may become defoliated as a result of moth infestation, although the effects of defoliation on plant growth, vigor and long-term survival remain unknown.

Although many browntail surveys and control efforts have been conducted within CACO over the last thirty years (see, for example, Snowden, 1986; Leonard, 1986; Samora and Whatley, 1987; and Anderson, 1989), virtually no quantitative data exist to indicate trends in the moth's distribution or abundance on the outer Cape. Only qualitative information on the perimeter of the past infestation is available, and associated census data are fragmentary at best. Survey methods are poorly documented, and survey tools and methodologies for estimating the density and distribution of this non-native insect remain inadequate and expensive. Browntail monitoring, implemented both immediately and over time as part of a long-term monitoring program, is needed in order to determine this insect's impact on native ecosystems.

Research Needs.

Monitor Moths: The University of Massachusetts is currently conducting a study of browntail moth ecology, with focuses on both the natural factors controlling browntail population dynamics and possible management methods. Following the 2002 completion of this study, annual surveys of browntail moth distribution and abundance on the outer Cape are needed in order to monitor the movement and severity of CACO's moth infestation over time.

The Browntail Moth, continued.

Study Browntail Impacts on Native Vegetation: Long-term monitoring plots need to be established to monitor host plant vigor, growth rates and survival, both in and outside of habitats containing browntail moths. Detailed information about browntail moth abundance in the test and control plots should be collected to determine if relationships exist between the various measures of moth abundance and damage to host plants, and to correlate the degree of defoliation with any associated impacts on plant growth and survival.

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Bullfrog Range Expansion.

Background.

When Lazell published his 1960s observations on the distribution of reptiles and amphibians on the outer Cape, bullfrogs (*Rana catesbeiana*) were restricted to the upper Cape, with one introduced group outside the boundaries of Cape Cod National Seashore in South Wellfleet. Today, however, bullfrogs are widely distributed throughout kettle ponds, temporary vernal pools and streams at least as far north as Truro. Additionally, although they were thought to be excluded from highly acidic habitats (pH < 5; see Freda, 1986), they seem to occur and breed quite successfully in CACO ponds with pH levels around 4.5. The absence of acid-tolerant green frogs (*Rana clamitans*) from these sites further suggests that they, and perhaps other native fauna, have been displaced by the larger predatory bullfrogs. Recent observations of bullfrogs in a number of vernal pools are of particular concern because species in these seasonal wetland communities have evolved over the last 10,000 years without large anuran predation, and are thus highly vulnerable to elimination by this invasive species. Research on the causes and effects of bullfrog expansion on the outer Cape is critically needed in order to develop effective management strategies for the protection of native amphibian species and for the preservation of CACO's aquatic biodiversity.

Research Needs.

A survey of bullfrog distribution on the entire outer Cape peninsula from Eastham to Provincetown is needed, followed by an examination of their ecological impact on faunal communities in CACO ponds and vernal pools. Using biological and chemical water quality data derived from other projects, the pattern of occurrence should be analyzed, with special attention given to water bodies within the present bullfrog range that do not have bullfrog populations and bodies of water that are on the margins of the present range. Emphasis should be placed on inter-species relations; however, the influences of aquatic chemistry and vegetative cover should also be investigated to explain the mechanism and possible limits of range expansion. Impacted native aquatic species should be identified, and field observation and analysis supplemented by experimental study in the lab, if necessary, to confirm hypotheses that are critical to the development of management strategies for bullfrog control and native species preservation.

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Freshwater Fish.

Background.

Cape Cod National Seashore contains a great diversity of freshwater aquatic habitats, including twenty kettle ponds, ten inter-dune ponds, one brackish impoundment and two rivers, that support about 15 species of freshwater and anadromous fishes.

These freshwater communities are subject to a variety of human influences that may be impacting the species composition and abundance of native fish populations. The Massachusetts Division of Fisheries and Wildlife (MDFW) maintains an active fishery enhancement program, which includes stocking waters with non-native fish and, in the past, liming kettle ponds. Recreational fishing for trout, bass and other game species is a very popular activity within Cape Cod National Seashore, and is often accompanied by the release of non-native baitfish into ponds. Non-native predatory fish probably consume native species and may also compete with native fish for resources. Water quality is threatened by passive water recreation and by extensive residential development along pond and river shorelines. Additionally, several different entities with different resource objectives have jurisdiction over the management of freshwater habitats within the CACO boundary.

Given the potential cumulative impacts of these influences, native fish populations may be seriously threatened. However, our ability to protect these species is at present severely hampered by a lack of baseline data on native freshwater fish. The MDFW has only sporadically sampled game fish, and only in the last two years have systematic freshwater fish surveys been initiated in Cape Cod National Seashore. A complete inventory of freshwater fish, followed by long-term monitoring, is necessary in order to identify and understand the issues facing aquatic resources within the park.

Research Needs.

A complete fisheries inventory of all freshwater habitats at CACO is currently underway through a cooperative agreement with the University of Massachusetts, Cooperative Fish Research Unit, and the United States Geological Survey-Biological Resources Division. Based on the data acquired in this study, a catalog of the occurrence, relative abundance and diversity of fish found within CACO's freshwater habitats will be developed, as well as species/habitat models for freshwater fish within the 20 kettle ponds and a protocol for continued monitoring. Long-term monitoring of freshwater habitats, with special emphasis on kettle ponds and estuaries, is needed in order to track changes in CACO's native fish populations over time.

The Gypsy Moth.

Background.

The gypsy moth (*Lymantria dispar*) was accidentally introduced into New England in the 1860s by a Massachusetts entomologist with a misinformed silk-making scheme. Since then, these invasive caterpillars have become a serious problem throughout much of the Northeast and even parts of the Midwest, resulting in the defoliation of millions of acres of hardwood forest, as well as significant tree mortality. Larvae prefer oaks (*Quercus* sp.), but will also feed on other species, including gum (*Eucalyptus* sp.), maple (*Acer* sp.), sassafras (*Sassafras* sp.) and, in severe infestations, beech (*Fagus* sp.), white cedar (*Chamaecyparis thyoides*) and pine (*Pinus* sp.). Outbreaks at Cape Cod National Seashore have been cyclical, with the last "high" period occurring in the mid-1980s. Up until 1965, gypsy moths on the outer Cape were treated annually with pesticides, but current management activity is limited to yearly population monitoring.

Research Needs.

The United States Forest Service (USFS) coordinates annual nationwide gypsy moth monitoring using a variety of sampling techniques, including traps, burlap bands and aerial surveys. Gypsy moth populations appear to be on the rise in Massachusetts, and continued monitoring using the USFS methods is necessary in order to track changes in the local abundance of this devastating invasive species and to formulate park-specific gypsy moth management actions.

Hunting Impacts.

Background.

The legislation that established Cape Cod National Seashore allows for hunting within the park, and species most commonly harvested in CACO include white-tailed deer (*Odocoileus virginianus*), cottontail rabbit (*Sylvilagus floridanus* and *S. transitionalis*), ring-necked pheasant (*Phasianus colchicus*; released yearly for hunting on CACO lands by the Massachusetts Division of Fisheries and Wildlife), Canada geese (*Branta canadensis*) and a large variety of other waterfowl. In order to maintain consistent safety regulations and bag limits, CACO has adopted the hunting regulations of the Commonwealth of Massachusetts (Massachusetts Division of Fisheries and Wildlife, 1990).

Little is known about the populations of, and levels of harvest experienced by, hunted animals within the park. Data on historic and current harvest levels in the park do not exist, nor has there been any effort to monitor population levels of hunted species. Consequently, the impacts of hunting on CACO ecosystems remain largely unknown. Small game hunting may compete with native predators and the possibility that such competition causes predators to shift to other prey, including state listed rare shorebirds, needs to be investigated.

Research Needs.

A multi-year study is needed to evaluate the ecological impacts of hunting at CACO. Data on harvest levels and hunting efforts by species should be collected, and long-term monitoring of hunted species initiated in order to detect population trends in correlation with harvest data. If it is found that hunting depresses populations of small game species, ecological studies of native predators such as the great horned owl (*Bubo virginianus*), red fox (*Vulpes vulpes*) and coyote (*Canis latrans*) should be undertaken to quantify their feeding habits and to determine the extent to which hunting competes with them for prey, and the extent to which these native predators may shift their foraging to other CACO species, including state listed rare shorebirds.

Research Cited.

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Marsh-Dwelling Shorebirds.

Background.

The estuaries and salt marshes of Cape Cod National Seashore are important breeding, stopover and wintering areas for a number of migratory shorebird species. In general, marsh-dwelling shorebirds concentrate where feeding efficiency is greatest and thus where invertebrate prey density or availability is highest, factors that are heavily influenced by sediment characteristics (Roman and Able, 1989; Brown, 1994; Grandy, 1972). Use of shallow water estuarine habitats by migrating shorebirds is also affected by a number of other habitat variables, including water salinity, depth and frequency of flooding, heterogeneity of the plant community, competition between bird species and the history of human impact in any given area.

Human activities have been shown to adversely affect avian populations in many ways, including altering distribution, habitat use and foraging patterns and increasing bird energy expenditures. The spatial distribution and volume of estuarine marshes that have sustained human-induced loss or degradation are, additionally, more susceptible to sea level rise and storm events, with corresponding adverse affects on waterbirds. Human-induced reductions in water level and salinity, like those in many CACO salt marshes, have also lead to vigorous expansion of common reed (*Phragmites australis*), which in turn has resulted in low breeding bird diversity and abundance. Finally, Atlantic oyster (*Crassostrea gigas*) and other shellfish culture alters birds' spatial habitat structure by introducing shellfish, racks, stakes, culture bags, marker poles and other equipment into open tidal flats. Research conducted to date on the ecosystem effects of aquaculture has been limited to studies of effects on sediment and benthic infauna; effects of oyster culture on bird populations have been minimally addressed (Kelly et al., 1996), but more comprehensive research is necessary to determine the impacts of aquaculture on shorebird populations in CACO.

Research Needs.

Monitor Migrant Shorebirds: Basic seasonal abundance data on migratory waterbird populations is fundamental to assessing the effects of aquaculture and chronic pollution, as well as catastrophic natural and anthropogenic events such as hurricanes and oil spills, on these bird communities. A protocol for measuring spatial and temporal patterns in frequency of occurrence, species richness, relative density and habitat use of waterbird assemblages in estuarine and brackish salt marshes is currently being developed with the United States Geological Survey. When integrated with other components of CACO's long-term ecological monitoring program, data acquired through the implementation of this protocol should allow managers to assess the impact of both natural and anthropogenic actions on bird use of wetlands for breeding, migration rest stops and non-breeding summering or wintering. Moreover, these data should be useful for predicting and evaluating the success of adaptive management actions such as salt marsh habitat restoration.

Marsh-Dwelling Shorebirds, continued.

Evaluate the Impacts of Aquaculture on Fisheries and Shorebird Habitat: The use of intertidal mud flats by fish (high tide) and migratory shorebirds (low and high tide) in relation to aquaculture operations within CACO needs to be investigated. Specific issues to be addressed include:

1. the selection or avoidance of aquaculture areas by fish and migrant shorebirds during each season;
2. differences in fish and shorebird diversity between open tidal flats and aquaculture areas;
3. temporal and spatial variation of fish and shorebird abundance on open tidal flats and aquaculture areas; and
4. intraseasonal shifts in the use of tidal flats and aquaculture areas as compared with overall abundance changes at specific sites, such as Nauset Marsh and Wellfleet Bay.

(See related project descriptions under “Red Fox, Small Mammal Prey and Shorebird Nest Predation,” “Shorebirds” and, in the Aquatic Ecology chapter, “Aquaculture Impacts on Estuarine Ecosystems.”)

Research Cited.

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Grandy, John W. IV. 1972. Winter colony of maritime black ducks (*Anas Rubripes*) in Massachusetts with special reference to Nauset Marsh, Orleans, Eastham. Unpublished doctoral thesis, University of Massachusetts.

Kelly, J.P., J.G. Evens, R.W. Stallcup and D. Wimpfheimer. 1996. Effects of aquaculture on habitat use by wintering shorebirds in Tomales Bay, California. *California Fish and Game,* 82, 160-174.

Roman, C. and K. Able. 1989. An ecological analysis of Nauset Marsh, Cape Cod National Seashore. NPS CRU, Rutgers University, New Brunswick, NJ.

The Northern Diamondback Terrapin.

Background.

Presently, there are only seventeen known marsh systems in Massachusetts that are home to the Northern diamondback terrapin (*Malaclemys terrapin*), a medium-sized salt marsh turtle that reaches its northern distribution limits in Cape Cod National Seashore. The diamondback terrapin is listed as "threatened" by the Massachusetts Division of Fisheries and Wildlife, with the state's largest terrapin population located in and around CACO.

Driven to the brink of extinction in Massachusetts by a gourmet taste for terrapin soup, the turtle now faces a different set of challenges. Although the harvest of diamondbacks is now illegal in Massachusetts, the species continues to experience high nest mortality and population decline as a result of human disruption and environmental degradation. Deep ruts created by off-road vehicles (ORVs) may trap migrant hatchlings, increasing both their chances of getting crushed by vehicles and their vulnerability to predation by gulls and crows, who have been observed standing on the edges of ORV tire tracks and scooping up baby turtles as they get caught in the ruts. ORVs also interfere with the nesting patterns of female turtles, who crawl towards high dunes with the intention of laying their eggs but return to the water at the slightest hint of threatening activity. This "false nesting," which may also be prompted by beach-goers and people walking on the dunes, disrupts the egg-laying process and reduces the viability of the clutch by prolonging the length of time that the eggs are retained by their mothers. Reduction of salt marsh habitat and alteration of water composition quality caused by dredging and channelization, loss of sandy beach habitat to erosion and pollution, and destruction of dune nesting areas also contribute to the decline of the Northern diamondback terrapin in Massachusetts, as do natural processes like the infiltration of rootlets from beach grass rhizomes into nests and eggs, mammalian predation and maggot parasitism.

Terrapin nesting surveys have been conducted on the outer Cape periodically since 1982; however, no in-depth terrapin studies have been completed since 1991. An up-to-date survey assessing the status and trends of the terrapin population, as well as detailing nest sites and nesting success, is needed to evaluate the need for further management actions to protect the Northern diamondback terrapin from extinction.

Research Needs.

A comprehensive field study of Northern diamondback terrapins in Wellfleet Bay is currently underway with the Massachusetts Audubon Society. Following this survey's completion, long-term monitoring of the species is needed in order to track population changes over time and to evaluate management actions designed to protect this threatened species.

Off-Road Vehicle Traffic Impacts on Beach Fauna.

Background.

Cape Cod National Seashore encompasses forty miles of pristine sandy barrier beaches and spits that attract millions of visitors every year, as well as diverse and, in some cases, rare wildlife communities. Because off-road vehicle (ORV) use on beaches predates the establishment of CACO in 1961, the enabling legislation for CACO permits the continued use of ORVs in the park. Until recently, vehicles used the 8.5-mile ORV corridor designated by the 1981/1985 ORV Management Plan to access recreational fishing sites. However, growing concern over nesting piping plovers (*Charadrius melodus*), federally designated as "threatened" in 1986, has resulted in a revision of the old ORV rule. The revised regulation closes a section of the original ORV corridor (Exit 8 to High Head North) and opens a previously restricted section of the outer beach for night fishing access (Coast Guard Beach to Longnook). This change could particularly increase ORV impacts to ocean beach invertebrates, which comprise a major portion of the natural beach community and an important part of the piping plover's diet. Given that optimum foraging habitat and prey availability appear to be prime factors in piping plover nest site selection and reproductive success and that the new ORV rule has a mandated provision to monitor and report on changing ORV resource impacts and conditions, an investigation into the impacts of this altered ORV traffic on beach invertebrates is necessary.

Research Needs.

The effects of ORV traffic on CACO's beach invertebrates are currently being investigated in conjunction with the University of Rhode Island, and standards with which to measure ORV impacts are being determined. Upon completion of this initial research, methods for characterizing ORV impacts to various fauna need to be developed and a long-term monitoring program needs to be implemented to identify and track the potential adverse effects of ORV use on CACO wildlife. If adverse effects on beach fauna populations or habitat are detected, management recommendations will need to be made for changes to the ORV corridor locations, traffic routes and/or allowed periods of use within the seashore.

Rare Invertebrates.

Background.

Named for its "tiger-like" behavior of chasing down and capturing prey with its long mandible, the Northeastern beach tiger beetle (*Cicindela dorsalis dorsalis*) is listed as an endangered species in the state of Massachusetts and federally classified as threatened. Historically, the tiger beetle was found along the Atlantic coastline from Massachusetts to Virginia, including several beaches within Cape Cod National Seashore (Nothnagle, 1989). Today, however, it can only be found at the extremes of its former range, in the Chesapeake Bay area adjacent to Maryland and Virginia and on a single beach on one of Massachusetts' offshore islands. Off-road vehicle (ORV) traffic is considered the prime cause of the beetle's decline up and down the Atlantic coast. ORVs kill adult beetles and larvae directly by crushing them, and they also impact the species by continually damaging under-sand larval burrows, forcing the larvae to reduce their feeding time and to expend a considerable amount of energy restoring the burrows. In addition, the proximity of the larval burrows to the high-tide line in mid-summer increases their chance of being washed away; a severe storm or early season hurricane at this time could potentially wipe out the entire state population, making the probability of extinction for the Northeastern beach tiger beetle very high. The Massachusetts Natural Heritage & Endangered Species program initiated a reintroduction effort on a second Massachusetts beach in 2000; however, long-term monitoring and expanded management and reintroduction efforts are critically needed to ensure the species' recovery.

In addition to the federally listed tiger beetle, six state-listed dragonfly and *Lepidoptera* species are also known to occur within the seashore (Carpenter, 1990; Mello, 1990), and because of the variable nature of invertebrate populations, many federal and/or state listed rare species may indeed be present that have not been located in previous studies. Without a comprehensive survey of CACO's invertebrate populations and focused monitoring efforts to continuously evaluate the status of these organisms, large-scale impacts to these rare species will likely go unchecked, as occurred with the Northeastern beach tiger beetle (Knisley et al., 1987).

Research Needs.

Develop Monitoring Plan: Development and implementation of a comprehensive long-term monitoring program for state listed rare invertebrates within CACO is critically needed for the protection of these species.

Evaluate Northeastern Beach Tiger Beetle Reintroduction Potential: The feasibility of reintroducing the Northeastern beach tiger beetle to the seashore needs to be assessed, with the cooperation of the Massachusetts Natural Heritage & Endangered Species program and the United States Fish and Wildlife Service recovery team. If reintroduction is deemed possible, CACO-specific management techniques should be developed and a reintroduction plan drafted.

Rare Invertebrates, continued.

Research Cited.

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Knisley, C.B., J.I Luebke, and D.R. Beatty. 1987. Natural history and population decline of the coastal tiger beetle, *Cicindela dorsalis dorsalis*. Virginia Journal of Science 38:293-303.

Mello, M.J. 1990. Survey of state-listed rare *Lepidoptera* on Cape Cod National Seashore Property. Lloyd Center for Environmental Studies, South Dartmouth, MA.

Nothnagle, P. 1989. Field survey of the tiger beetles (*Cincindelidae, Cincindela*) of the Cape Cod National Seashore. Windsor, VT.

Red Fox, Small Mammal Prey and Shorebird Nest Predation.

Background.

Red foxes (*Vulpes vulpes*) are a major predator on the eggs and young of ground-nesting birds in Cape Cod National Seashore's barrier beach habitats. The traditional management response to piping plover (*Charadrius melodus*) and tern (*Sterna* sp.) nest predation has included predator removal and harassment, as well as efforts to reduce the vulnerability of nests by erecting fenced enclosures around the nest sites. A better understanding of the factors that influence nest predation is needed, however, in order to formulate more effective management strategies. Many researchers have demonstrated that nest predation may be influenced by the abundance of alternate prey. An early study of predator-prey relationships in an Iowa waterfowl nesting area suggested that the nesting success of the blue-winged teal (*Anas discors*) was buffered by the abundance of small mammals and in Wisconsin, unpublished data also indicate that waterfowl nesting success is positively related to the abundance of small mammals. In Utah, radio-marked striped skunks (*Mephitis mephitis*) demonstrated a shift in foraging strategy from a "widely searching" to a "sit and wait" behavior that coincided with the increased availability of alternate prey later in the nesting season. That behavioral shift reduced the time skunks spent "widely searching," thus decreasing the probability of them encountering nests. In Sweden, red fox shifted from their main prey of small mammals to alternate prey such as willow grouse (*Lagopus lagopus*) and then to oldsquaw (*Clangula hyemalis*) eggs and ducklings following a crash in small mammal populations. Similarly, large variations in the breeding success of brent geese (*Branta bernicula*) in Russia appear to have been closely linked over a 33-year period with the abundance of small mammals. Given the importance of CACO as a nesting site for endangered shorebirds and the abundance of research worldwide that points to a relationship between small mammal abundance and waterbird nest success, a closer look at CACO's own predator-prey interactions is necessary in order to better manage its shorebird populations.

Research Needs.

Study Red Fox Ecology: A study of red fox distribution and feeding ecology on the outer Cape is currently underway; however, credible scientific data is also needed on red fox habitat use, prey interactions and interactions with coyotes. Once sufficient data has been collected, management strategies should be developed to address red fox predation on piping plovers, inappropriate contact between foxes and park visitors (begging and frequent encounters in visitor areas), incidence of mange and pressure from other agencies to use lethal control methods.

Red Fox, Small Mammal Prey and Shorebird Nest Predation, continued.

Study Small Mammal Abundance in Relation to Shorebird Nest Predation: The abundance and composition of small mammal species, hereby defined as shrews (*Blarina* sp.), voles (*Microtus* sp.), mice (*Peromyscus* sp. and *Mus* sp.) and rabbits (*Sylvilagus* sp.), needs to be determined in several habitat types, including sandplain grassland, coastal heathland, shrub thicket and oak-pine forest. Standard small mammal trapping techniques should be employed to determine habitat-specific abundance during the plover and tern nesting season (May-July). This data should then be compared to piping plover and tern nest predation rates in order to define the relationship between small mammal abundance and shorebird predation at CACO.

(See related project descriptions under “Shorebirds” and “Marsh-Dwelling Shorebirds.”)

Reptiles and Amphibians.

Background.

Despite their important roles as bioindicators and as integral components of terrestrial and aquatic

ecosystems on Cape Cod, a comprehensive survey of reptile and amphibian populations within Cape Cod National Seashore has never been completed. Our current knowledge of local populations is based upon Lazell's (1972) surveys of the entire Cape and Islands region, Jones' surveys of CACO reptiles and amphibians (1992), Seipt's (1987) studies of state listed rare species, Portnoy's inventory of amphibians associated with temporary ponds (1986), the Massachusetts Audubon Society's terrapin studies (Shipley and Prescott, 1989) and casual observations. A unique assemblage of amphibians and reptiles inhabits the outer Cape, due in part to the area's insular nature and glaciated past, and these animals' sensitivity to changes in their environment makes thorough, frequent monitoring especially crucial to their survival. Amphibian populations, in particular, have exhibited dramatic population declines worldwide, variously attributed to development impacts, global climate change, acid rain and attendant shifts in habitat, predation and/or competition. Major concerns on the Cape include habitat disruption associated with the effects of groundwater withdrawal on aquatic breeding and feeding areas, increased mortality from highway traffic (which is particularly acute during breeding migrations and dispersal from breeding sites), physical trampling of upland and wetland habitat, human recreational use of breeding pools and loss of upland habitat used by vernal pool breeders to residential development. Insular reptile populations are also highly vulnerable to development on the outer Cape, with heightened habitat isolation and direct mortality (e.g. road kills) inevitable as human activity increases. Complete, up-to-date surveys of CACO's amphibian and reptile populations are thus critically needed in order to protect these animals and their critical habitat.

Research Needs.

An initial amphibian inventory was recently completed by the United States Geological Survey, and snake and aquatic turtle surveys are currently underway. Once these baseline inventories have been completed, long-term monitoring should be implemented in order to detect and track changes in the composition and abundance of these sensitive species over time, and to inform management decisions for their protection.

Research Cited.

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Reptiles and Amphibians, continued.

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Portnoy, J.W. 1986. Vernal ponds of the Cape Cod National Seashore: Location, water chemistry, and *ambystoma* breeding biology. Cape Cod National Seashore, Wellfleet, MA.

Seipt, Irene. 1987. An inventory of the eastern spadefoot toad (*Scaphiopus holbrooki*) and the four-toed salamander (*Hemidactylium scutatum*) on outer Cape Cod. Center for Coastal Studies, Provincetown, MA.

Shipley, S. and R. Prescott. 1989. 1989 diamondback terrapin study of Wellfleet Harbor. Wellfleet Bay Wildlife Sanctuary, Massachusetts Audubon Society, South Wellfleet, MA.

Seals.

Background.

Centuries ago, large colonies of seals (*Halichoerus* and *Phoca* sp.) populated the shores and coastal waters of Cape Cod. In the mid-1800s, however, the seals, with their voracious appetite for fish, were viewed as a threat to the commercial fishing industry and were hunted for a bounty. Such hunting decimated the population of seals on Cape Cod. Not until 1962, when government sanctioned bounty hunting was finally put to an end in Massachusetts, did seals return to this area. These days, seals are protected under the Marine Mammal Protection Act of 1972 and increasing numbers of harbor and gray seals are once again year-round residents of Cape Cod. With the increase in animals has come an increase in human/seal interactions and, again, seals are starting to be viewed as major competitors for food and space. Accurate information on the population, distribution and dominant prey species for western North Atlantic seals is crucial to the resolution of these renewed seal concerns and to the continued protection of the indigenous marine mammals.

Research Needs.

A study of seal distribution and diet is currently underway at Race Point in Provincetown. Upon its completion, long-term seal monitoring is needed in order to assess changes in Cape Cod seal predation and population patterns over time.

Shorebirds.

Background.

Cape Cod National Seashore contains the largest colony of state listed rare least terns (*Sterna paradiseaea*) in New England, the largest colonies of state listed common and arctic terns (*Sterna hirundo* and *antillarum*) in Massachusetts, and a small but significant population of the federally

endangered roseate tern (*Sterna dougallii*). CACO also provides significant nesting habitat for the federally threatened piping plover (*Charadrius melodus*). The breeding success of all of these species is negatively affected by off-road vehicles, pets, and native and feral predators, and pre-migratory feeding, essential to meeting the energy demands of these shorebirds during migration, is often interrupted by pedestrians, pets and recreational activities with poorly known consequences. Because all of these shorebird species regularly come into contact with visitors to CACO, shorebird management requires intensive monitoring and protection, education of beach-users, enforcement of beach closures and wildlife regulations, and involvement with the media, off-road vehicle user groups and conservation organizations. The success of these management actions is key to these species' recovery. Much of the piping plover's recovery to date, for example, has been due to recovery in the state of Massachusetts, with CACO alone accounting for over ten percent of nesting pairs and over fifteen percent of plover productivity statewide in 1997 and 1998. While management efforts have thus been very successful in some areas, funding shortages have prevented adequate coverage of all shorebird nesting sites within the seashore.

Evolutionary adaptations of shorebirds that minimize the effects of predation include re-nesting, anti-predator behaviors and cryptic coloration of males and females. During the last 300 years, however, Cape Cod has been transformed from largely pristine wilderness to an intensively farmed area (Dunwiddie and Adams, 1995) and most recently, to a fragmented suburban landscape with dense human settlements. Coupled with these landscape changes have been changes in the composition of predator communities and in the abundance of nearly all predator species. Piping plovers and colonial nesting terns are presently exposed to different types of predator communities than existed during pristine times, and the birds' evolutionary defense mechanisms may no longer be adequate to protect them against these altered predation patterns. The American crow (*Corvus brachyrhychos*) benefits greatly from agricultural and suburban developments, like those on Cape Cod, that provide artificial sources of food and trees for nesting (Schorger 1941). Not surprisingly then, American crows have been identified as a major cause of reproductive failure among piping plovers in CACO (Melvin et al., 1992). In 1994 and 1995, crows accounted for 67 percent of nests destroyed by predators (Jones, 1997). Further, Sullivan and Dinsmore (1990) found that egg predation was higher on bird nests placed within home ranges of breeding crows than on nests placed at random

Shorebirds, continued.

locations outside of home ranges. While good information exists on crow ecology in upland habitats, research on American crow distribution, abundance and foraging ecology in Atlantic coast barrier beach ecosystems is needed to assess the threat of crow predation to threatened shorebird species.

Research Needs.

Monitor Nesting Shorebirds: Existing breeding shorebird surveys need to be expanded to include North and South Beaches in Orleans and Chatham, and additional in-depth monitoring is needed to determine the causes of low tern and gull productivity at New Island in Nauset Marsh. Special attention should be given to monitoring all areas within the CACO boundaries on the dates requested by the Massachusetts Division of Fisheries and Wildlife, and census data and site information should be recorded in CACO's Geographic Information System to facilitate comparisons of nesting site locations and preferences over time.

Analyze Nesting Habitat: Data on beach characteristics have been collected in conjunction with piping plover monitoring over the last few years; however, additional data describing beach configuration and the spatial characterization of the intensity of nesting disturbances are needed in order to refine the definition of suitable habitat for plovers and to identify sites that meet this more specific criteria. Based on these findings, a habitat suitability index for shorebird nesting should be developed and tested.

Assess Crow Depredation: Research is needed to determine crow population parameters and productivity, to describe the foraging ecology of crows and to evaluate chronological changes in diet and movements that might affect predation rates on barrier beach nesting birds. Foraging ecology should be determined through radiotelemetry and visual monitoring, and breeding population densities should be estimated by intensive searches for nests. After these initial investigations have been completed, a long-term monitoring protocol should be developed for this species.

(See related project descriptions under “Red Fox, Small Mammal Prey and Shorebird Nest Predation” and “Marsh-Dwelling Shorebirds.”)

Research Cited.

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Shorebirds, continued.

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Sullivan, B.D. and J.J. Dinsmore. 1990. Factors affecting egg predation by American crows. J. Wildlife Management. 54:433-437.

Schorger, A.W. 1941. The crow and the raven in early Wisconsin. Wilson Bull. 53:103-106.

Small Mammals.

Background.

Cape Cod National Seashore contains a number of relatively uncommon and insular terrestrial habitats, which may support an equally diverse and important mammalian fauna; very little is known, however, about the abundance and distribution of small mammals within the park. A list of 28 species found within CACO has been developed (Jones, 1990) and rodent monitoring was recently conducted within the park's more common habitat types, but no voucher specimens exist in CACO's natural history collection and no park-wide small mammal reconnaissance has been conducted. A geographically- and ecologically-complete inventory of CACO's small mammals, followed by long-term monitoring, is thus critically needed in order to assess the impacts of habitat fragmentation, annual small game hunting and other potential threats to the park's small mammal populations.

Research Needs.

A small mammal inventory focusing on rodents in common habitat types was conducted in 2000 and 2001; however, quantitative and qualitative information on less common habitats (e.g. Atlantic white cedar and red maple swamps, beech forest) and other mammal groups (e.g. bats and other insectivores, rabbits, hares) is still needed. Long-term monitoring of all small mammals and small mammal habitats within the park is necessary in order to detect and track changes in these populations over time.

Research Cited.

Jones, K. 1990. Mammal Inventory, Cape Cod National Seashore. Cape Cod National Seashore, South Wellfleet, MA.

The Spotted Salamander.

Background.

A significant component of Cape Cod's aquatic ecosystems, mole salamanders (*Ambystomidae*) are considered highly vulnerable to acidification because of their near-exclusive use of temporary isolated wetlands for breeding. On the Cape, these breeding ponds are poorly buffered and the presence of sphagnum and pine, oak and maple litter results in highly acidic water (pH 4.5 to 5.5) with no reserve alkalinity and high color. Recent work by Portnoy (1990) has demonstrated a high level of acid tolerance among Cape spotted salamanders (*Ambystoma maculatum*), but also a clear sensitivity of embryos to the combination of low pH and high concentrations of naturally occurring polyphenolic compounds. It is hypothesized that further reductions in the pH of highly colored sites due to acid rain (presently measured in CACO at pH 4.3) may substantially reduce embryonic survival and recruitment rates within isolated amphibian populations. Since the widely distributed spotted salamander is the only amphibian whose breeding abundance and embryonic survival have been systematically inventoried throughout Cape Cod National Seashore, a clear opportunity exists to use this baseline to evaluate the biological effects of potential acidification on this species.

Research Needs.

Although adult salamanders are fossorial and therefore difficult to find, they do assemble to mate and oviposit at traditional breeding ponds and pond complexes within a fairly predictable time period in early April. Their reproductive output, if not their adult population size, is thus countable on an annual basis and work elsewhere has shown these egg counts to be a good index of breeding female abundance. When coupled with coincident water chemistry (pH, alkalinity, color and tannin-lignin), they should sufficiently reflect biologically significant changes in water chemistry over time. Long-term monitoring of CACO's spotted salamander population through the use of egg counts is thus needed to assess the population's overall health and response to changing water quality. If declines are suspected as a result of water chemistry changes, results should be confirmed with egg mortality studies to determine if the cause is indeed due to changes in embryonic mortality rates. Additional research may be necessary to assess survival and recruitment in the adult population.

Research Cited.

Portnoy, J.W. 1990. Breeding biology of the spotted salamander in acidic temporary ponds at Cape Cod, USA. Biological Conservation, 53:61.

Strandings.

Background.

Records of marine mammal strandings on Cape Cod date back hundreds of years – in fact, harvesting stranded whales for oil formed the basis of Wellfleet's early economy – and cetacean and sea turtle strandings still regularly occur within Cape Cod National Seashore. Many of the stranded animals are federally listed as threatened or endangered species and, in some cases, the cumulative loss of these individuals to stranding may have an impact on the population as a whole.

Marine mammal strandings are typically caused by illness or injury, but human interaction (through fishing gear entanglement or marine debris ingestion, ship strike and even gunshots), stormy weather, and the swift, extreme tides in Cape Cod Bay also appear to be factors. Typically, cetaceans migrate to the area to feed on the rich stores of plankton and fish in the bay or at the nearby Stellwagen Bank National Marine Sanctuary. When the animals become fouled in gear, normal breathing, feeding and movement may be impaired or stopped completely; weakened by this inability to feed or breath properly and exhausted from the excess drag created by trailing, tangled gear, entangled marine mammals may be unable to prevent themselves from washing ashore. Heavy seas following storms can also leave animals exhausted, disoriented, or separated from their group, and the rapidly changing bay tides can leave dolphins and porpoises stranded in marshes or mudflats where, hours before, they were feeding plentifully on fish that had come in on the high tide. The very process of stranding can be catastrophic for a cetacean, even for one who has simply lost its way and become trapped by an outgoing tide. Although many stranded mammals come ashore alive, the beaching prompts a cascade of physiological changes, often resulting in shock and death.

Mass strandings, involving anywhere from a few to several hundred animals, regularly occur in several parts of the world (primarily Australia, New Zealand, and Cape Cod), yet so far there is no universally accepted, comprehensive explanation for this phenomenon.
In many cases, these animals show no obvious signs of health problems other than those resulting from the stranding itself. It is hypothesized that, because the species typically involved in mass strandings are extremely social, the bonds that hold groups together are perhaps strong enough to supercede the survival instincts of individual animals. Once animals start coming ashore at a mass stranding event, it is extremely difficult to stop the process from continuing and escalating. Affected animals will relentlessly follow one another ashore, even when there is clear access to open water. Although mass strandings typically occur during winter months and at times of severe weather, they can in fact occur at any time of year and under any conditions.

Strandings, continued.

Sea turtles in our region do not typically come ashore unless they are seriously debilitated. During the warm summer months, several turtle species ride the Gulf Stream north from the Caribbean Sea and the Gulf of Mexico to feed on the abundant food supply in Cape Cod Bay. As water temperatures drop in the late fall and winter, the turtles' body temperatures can fall below their tolerable limits. In a condition similar to hypothermia, the animals become unable to swim or feed and become increasingly susceptible to dehydration and disease. Instead of migrating south to warmer waters, "cold-stunned" turtles often become trapped in Cape Cod Bay, drifting helplessly with the winds and currents until they wash ashore. During a typical winter, several dozen live sea turtles wash ashore on Cape beaches. If these turtles are recovered and treated soon enough, they have a good chance of survival.

Research Needs.

Cape Cod National Seashore works closely with the National Marine Fisheries Service, the New England Aquarium, the Center for Coastal Studies and Massachusetts Audubon Society's Wellfleet Bay Wildlife Sanctuary to respond to live strandings on the outer Cape. Live animals are assessed, and then either transported to institutions for rehabilitation, returned to the water with guidance from experienced rehabilitation personnel or, in some cases, euthanized. Necropsies are performed on dead animals when appropriate. Further research into the causes of mass strandings is needed, as is a long-term evaluation of the success of current rescue techniques.

Terrestrial Birds.

Background.

Landbirds, because of their high body temperature, rapid metabolism rate and high ecological position on most food webs, may be excellent indicators of the effects of environmental change in terrestrial ecosystems. Furthermore, their diurnal nature, discrete reproductive seasonality, intermediate lifespan, and abundance and diversity in virtually all terrestrial habitats favor widespread monitoring of their population and demographic information. It is not surprising, therefore, that landbirds have been selected by the National Park Service to receive high priority for monitoring because of their potential as sensitive indicators of local, regional and global environmental change.

The importance of Cape Cod as a breeding and migration stopover site for neotropical migrant landbirds and many other state listed rare bird species is well-known, but not quantified. In the past, available data on terrestrial birds at Cape Cod National Seashore has focused on migratory and wintering periods without a qualitative or quantitative database on nesting landbirds. Although extensive research has been done on CACO's shorebird populations, no complete inventory of CACO's terrestrial birds exists, and as a result management decisions must regularly be made with minimal information about, and without consideration for, terrestrial bird populations. In addition to standard baseline information about the terrestrial bird species occurring within the seashore, avian productivity and survival data is needed to: identify the stage(s) in bird life cycles at which changes in population dynamics are taking place; define thresholds and trigger points for research and/or management actions regarding landbird population declines; facilitate the planning of management actions and conservation strategies to reverse population declines; and aid in evaluating the effectiveness of such actions. Landbird population performance will also be a useful measurement in evaluating the success of land management actions designed to mimic natural landscape patterns, such as prescribed burns, and in evaluating the effects of specific human-related and natural events on terrestrial bird populations.

Research Needs.

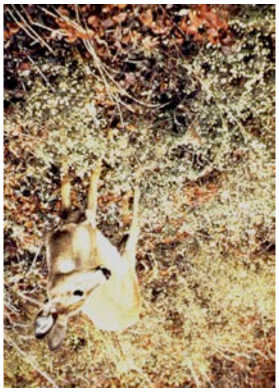
Inventory Nesting Birds: Until recently, landbird monitoring at CACO was limited to one annual five-hour survey along a 25-mile stretch of road from Eastham to North Truro. In 2001, however, a more expansive two-year terrestrial breeding bird survey was initiated. Following this initial inventory, long-term monitoring is needed to track changes in CACO's landbird population and to evaluate the success of CACO management actions intended to protect these species.

Terrestrial Birds, continued.

Monitor Migrant Species: The Beech Forest in Provincetown is a well-known stopover spot for migratory landbirds, attracting hundreds of birdwatchers in late May every year. Amateur ornithologists have observed a decline in the Beech Forest's bird populations over recent years, but such changes have not been scientifically quantified. Migratory bird populations in the Beech Forest, and other CACO areas where geography and habitat concentrate migrants, need to be monitored in order to detect and mitigate population declines.

Monitor Avian Productivity and Survival: A five-year project investigating the productivity and survival of a number of target avian species, including both neotropical migrants and permanent residents, began in 1999. Continued long-term monitoring following the project's completion in 2003 is necessary in order to determine annual changes and long-term trends in the population and demographic parameters of CACO's landbirds.

The White-Tailed Deer.



Background.

Although white-tailed deer are one of the most popular and important terrestrial mammals within Cape Cod National Seashore, relatively little ecological or biological information exists about the park's deer population. Hunting is a traditional activity on the outer Cape, and the Massachusetts Division of Fisheries and Wildlife manages the population by setting harvest quotas and hunting season dates. Deer are harvested during the fall with three-week archery, one-week shotgun and two-day primitive firearms seasons. The annual limit is two deer per season; one antlerless deer per year can be taken by permit only. Other than evaluating the sex and general age characteristics of the harvest, however, no monitoring is conducted. Data on the deer and hunting efforts are critically needed to identify and adequately evaluate anthropogenic and natural changes to CACO's white-tailed deer population.

Research Needs.

A baseline survey of deer abundance and distribution in CACO, followed by long-term monitoring, is needed. Harvest rate, sex, age, weight, antler-beam diameter of yearling males and female reproductive rates should be included in the monitoring protocol. Specific questions to be addressed include:

1. Are deer numbers increasing in CACO, as suggested by the substantial increase in the annual deer harvest over the last ten years?
2. Are distribution patterns for white-tailed deer changing in the seashore?
3. Are hunter efforts changing and, if so, how are those changes affecting the abundance and composition of the herd? What role does hunting play in regulating the deer population?
4. How are deer impacted by increasing residential development in, and visitation to, the outer Cape?
5. How will changes in landscape and vegetation influence deer population dynamics?
6. What are the ecological effects of increasing deer densities? Are plant species being eliminated as a result of browsing by deer? Are deer adversely affecting forest-nesting birds?

(See related project descriptions under "Hunting Impacts.")

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Natural Resource Management

Fire Management.

Background.

Wildfires have been a component of upland ecosystems on Cape Cod for thousands of years. Prior to European settlement, Cape vegetation was frequently burned by both natural and anthropogenic wildfires (Backman, 1984; Day, 1953; Patterson and Sassman, 1988), and it is likely that fire has played a role in the spatial heterogeneity of upland vegetative cover on the outer Cape. Since the establishment of Cape Cod National Seashore in 1961, however, CACO staff have aggressively suppressed all wildfires within the seashore's boundary, limiting total burned acres to less than 40 hectares in as many years. The effect of this full-suppression policy on forest fuels and vegetative communities within the seashore remains unknown, but it is hypothesized that complete fire suppression may lead to more uniform forest cover, the decrease and eventual disappearance of fire-dependent communities such as grasslands and heathlands, an increase in surface water acidity and an unprecedented accumulation of organic matter with the potential to fuel an uncontrollable and highly destructive wildfire.

An average of 10 to 15 ignitions occur each year at CACO, all the result of human carelessness or mischief (Dosmann and Patterson, 1990). When paired with climate and forest fuel factors, this human impact can create the potential for hazardous wildfires on the outer Cape. The abundance of black huckleberry (*Gaylussacia baccata*) in much of the park's pine-oak forests also presents a fire management concern, because it contains volatile oils that burn explosively when ignited. Since 1985, CACO and cooperative research units at the University of Massachusetts have been conducting prescribed burning and collections of vegetation response data in a 7-hectare site in South Truro. This research has, in turn, led to the development of several Cape-specific fuel models, which are currently being tested under prescribed burning conditions on one- to five-acre plots at the Truro site. Burns took place in 1999, 2000 and 2001, and are planned to continue through 2004.

Research Needs.

Map Hazard Fuels: The accumulation of forest fuels at CACO has increased dramatically in recent years, largely as a result of insect, wind and disease damage. Pitch pine (*Pinus rigida*) communities have been particularly hard hit, with turpentine beetles (*Dendroctonus* sp.) leading to blue stain fungal infection in stands as large as twenty hectares. Updated hazard fuel mapping and sampling, including biomass measurements, are needed in order to make informed decisions regarding fire management in the park.

Assess Forest Pest Damage: The United States Forest Service (USFS) coordinates annual nationwide gypsy moth monitoring using a variety of sampling techniques, including traps, burlap bands and aerial surveys. Gypsy moth populations appear to be on the rise in Massachusetts, and continued monitoring using the USFS methods is necessary in order to track changes in the local abundance of this devastating invasive species and to formulate park-specific gypsy moth management actions. Annual surveys of browntail

Fire Management, continued.

moths and other forest pests are also needed in order to inventory and assess the damage caused by insect pests in CACO forests. When possible, survey results should be linked to environmental factors such as temperature and drought status in order to provide resource managers with a tool for predicting damaging infestations and subsequent hazard fuel accumulations.

(See related project description under “The Browntail Moth” and “The Gypsy Moth” in the Wildlife Ecology chapter.)

Investigate Suppression Impacts: Although it is hypothesized that CACO’s policy of complete wildfire suppression could precipitate a decline in habitat heterogeneity or result in a major uncontrolled wildfire with extensive natural and cultural repercussions, little quantitative information about the impacts of fire suppression on the outer Cape actually exists. A thorough investigation of fire suppression impacts on Cape ecosystems is needed, followed by long term monitoring of CACO’s plant communities and computer modeling of future vegetation trends. The fuel loading transects completed by Patterson, et al. in 1984 should be re-surveyed, and research should be undertaken to determine the present level of fuel loading in the park, as well as the average rate of accumulation.

Test Fuel Models for Coastal Pine Communities: Five years of research on huckleberry (Patterson, et al., 1984) has produced data on vegetation response to fire, fire rate-of-spread and fireline intensity for prescribed burns in the huckleberry understory of oak-pine forest, and ongoing research on the effects of fire on coastal pine communities has resulted in the development of CACO-specific fuel models with huckleberry components. Field validation trials are currently in progress at one site in South Truro; however, at least four discrete areas need to be tested in order to check the validity of these models. Continued testing of custom fuel models is thus necessary.

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Land Use Mapping.

Background.

The last thirty years have brought unprecedented population growth to Cape Cod, along with a boom of residential and commercial development that shows little sign of slowing. Between 1970 and 2000, the number of year-round Cape Cod residents doubled to 200,000, the number of Cape housing units increased by a dramatic 76 %, and despite the ability of Cape Cod National Seashore to protect pristine land inside its boundaries from major development, increasing numbers of privately-owned seasonal cottages within the park have been, and continue to be, redeveloped and converted to year-round residences. Forest clearance, extended pavement and new roads, additional on-site wastewater disposal and increased use of pesticides and fertilizers in areas within and adjacent to CACO all pose a serious threat to the outer Cape's aquatic and terrestrial resources. Rather than attempting to assess each development project individually, Geographic Information System mapping and analysis are expected to provide a more systematic, comprehensive and scientifically credible way to assess the cumulative impacts of development on outer Cape Cod.

Research Needs.

Regular land use mapping and analysis, using CACO's GIS, is needed to monitor and assess rapid land use changes on the outer Cape. Although preliminary data can be acquired from MassGIS (Commonwealth of Massachusetts, EOEA -- land use, wetlands and conservation lands data from 1999 are now available for internet download), sources of impact such as new construction, subdivisions, large paved areas, lawns, underground storage tanks and new septic systems need to be mapped from aerials, field visits and assessor's records. The GIS analysis should include hydrologic (groundwater and surface water flow direction and velocities) and geologic (soils and surficial geology) information to predict development effects on downgradient wetlands, ponds and estuaries. Additionally, specific GIS Software tools and applications for predicting groundwater effects need to be identified and tested for use at CACO.

Long-Term Weather Database.

Background.

The success of nearly all ecological field research and monitoring at Cape Cod National Seashore, as well as the investigation of oil spills, wildfires, insect dispersion and other unexpected impacts to CACO natural resources, is dependent upon accurate and accessible meteorological information. Presently, precipitation data are recorded continuously at the Truro National Atmospheric Deposition site and Race Point Ranger Station, and National Oceanic and Atmospheric Administration observations are collected at weather stations in Provincetown and Chatham. Fire weather observations including temperature, RH, precipitation, fuel stick moisture, and wind speed and direction are collected hourly during fire season on a data logger, which is downloaded as needed for fire indices determinations.

Research Needs.

A standardized protocol for monitoring meteorological and atmospheric conditions at CACO is currently being developed in partnership with the United States Geological Survey. Upon its completion, long-term monitoring needs to be initiated and subsequent data integrated, along with past and present fire weather observations, into a comprehensive weather database. As an important tool for enhancing research and information across the resource management spectrum, the database should be formatted for easy retrievability by CACO resource managers.

Vegetation Mapping.

Background.

Up-to-date vegetation maps are an important component of vegetation and fuels management, and are vital to predicting ecological change stemming from natural processes, unplanned human intervention and habitat restoration projects. Accurate historical vegetation cover maps are also necessary to track changes in plant communities over time and to provide context for other kinds of habitat mapping and research within Cape Cod National Seashore's Inventory & Monitoring program. Vegetation cover mapping needs to be completed at ten-year intervals (and in areas of rapid change, every five years or less) in order to accurately correlate information with other monitoring protocols. With the cooperation of the University of Massachusetts, an updated vegetation map is currently being generated based on aerial photos from 2000; the next update should occur by 2010. Traditional hard-copy photogrammetry methods are still being utilized, but as high resolution satellite imagery becomes more available and new remote sensing classification methods build proven track records, these methods may also be considered.

Research Needs.

Restore Historic Maps: Historical cover and vegetation maps are a valuable source of information which, if their methods and accuracy can be verified, may add decades to the long-term record of vegetation and land use changes on outer Cape Cod. Historical land cover and vegetation map sources for the outer Cape exist in various forms: hard-copy vegetation polygon maps from 1958 and 1977 (with partial digital versions), U.S. Coastal Survey Maps from 1836-1868 and 1943, and complete aerial photo sets from 1938, 1947, 1960, 1977 and 1987. Other recent photo sets are also becoming available from the Commonwealth of Massachusetts. Information from each of these sources needs to be digitized, interpreted, checked against contemporary evidence and verified, as well as metadata prepared. The final geographic data standard dictates ArcInfo format, UTM coordinate system, North American Datum 1983 (usable in Arcview 3.2a and subsequent versions of ESRI software).

Verify Current Maps: Current and future vegetation mapping efforts need field verification, and statistical field sampling (including ordination analysis) is needed for a more precise record of vegetation type composition. Once sampling methods have been standardized, field sampling and verification efforts should be repeated at regular intervals. Current data should also be compared to historical information using descriptive methods. Additional query/analysis may be possible based on specific questions of habitat change and wildlife dynamics, such as trends in heathland, wetland and forest composition, threatened species productivity, predator interactions and forest pests.

Additional Projects in Natural Resource Management.

Many natural resource management projects at Cape Cod National Seashore also fall under other areas of study. See below for additional natural resource management projects listed in this catalog under their primary field:

Aquatic Ecology

Atmospheric Monitoring

Coastal Geomorphology

Plant Ecology

Additional Projects in Natural Resource Management, continued.

Wildlife Ecology

Cultural Resource Management

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Cultural Resource Management

Cultural Resources at Cape Cod National Seashore.

The Cape's prominent position in the Atlantic has long made it a key landmark for human habitation, and archaeological sites testify to over 9,000 years of occupation. By the1600s, the Wampanoag tribes used or inhabited all of the lands now contained within the national seashore and in 1620, the Pilgrims made their first landfall on the shores of the outer Cape. With European settlement, Cape Codders took to the sea, creating a dynamic whaling and fishing industry, as well as a long and famous tradition of shellfishing. The many lighthouses and Coast Guard stations that dot Cape shores reflect this heritage; the beauty and sense of solitude that they have come to represent continues to inspire artists and writers in what is now a centuries-old Cape Cod arts tradition.

Historic Structures

From lighthouses and life saving stations to dune shacks and original examples of the Cape Cod architectural style, the many historic structures within Cape Cod National Seashore serve as a tangible reminder of the region's rich human history. A total of 62 federally-owned buildings at the seashore are eligible for the National Register of Historic Places, and approximately 240 privately-owned historic buildings within park boundaries have been identified by the Historic American Buildings Survey. Ten of the federally-owned historic structures are open to the public for regularly-scheduled interpretive programs, including: the Atwood-Higgins complex, a nine-building homestead dating from the early eighteenth century; nineteenth-century whaling captain Edward Penniman's house and barn; the Old Harbor Life-saving Station; and the Highland, Nauset and Three Sisters lighthouses.

Due to funding shortages, adequate assessments of the condition and significance of many of CACO's historic structures have not been completed and, as a result, some have been destroyed or extensively altered. Maintenance and preservation efforts for nearly all of the park's historic buildings have also been severely hampered by a lack of funding, underscoring the need for increased public partnership in the stewardship of these valuable cultural resources.

Cultural Landscapes

Cape Cod National Seashore's varied vernacular landscapes are living illustrations of the traditional character of the outer Cape, and of Cape Codders' changing attitudes towards the land (and sea) around them. Although some of the seashore's significant cultural landscapes, such as the Pamet cranberry bog and the open fields of Fort Hill, have been identified for preservation, a comprehensive inventory of historic landscapes at CACO has never been completed. Without baseline information as to the location and significance of CACO's cultural landscapes, many may be lost. Because the form and value of these landscapes may be obscured as they evolve, even after the land itself has been designated for preservation, a comprehensive and scientifically sound management plan is also critically needed for the preservation of these historic resources.

Archaeological Resources (including submerged sites)

From colonial tavern foundations to prehistoric garbage pits, archaeological sites on the outer Cape have contributed much to the historical record of human activity on Cape Cod. In addition to the seashore's numerous land-based archaeological sites, the waters off the coast of Cape Cod National Seashore also contain a unique wealth of submerged shipwreck sites. The Cape's prominence on the Eastern seaboard, coupled with its notoriously severe weather and ever-shifting offshore shoals, has been responsible for over 3,000 shipwrecks in 300 years of recorded history; from time to time, winter storms still unearth the weathered remains of old wrecks on the outer beach.

The complex nature of land ownership at CACO, both on- and offshore, can create quite a challenge for the preservation of outer Cape archaeological resources. Land ownership within park boundaries varies between the National Park Service, the state of Massachusetts, individual towns and private citizens. Thus, some of CACO's archaeological sites extend from federal onto private lands, with the potential for ground disturbance that could destroy or degrade the information contained at the sites. Additionally, shoreline retreat and a rising sea level are submerging land-based resources and changing the national seashore's offshore boundary (defined as 0.25 miles from the shoreline.) As a result, some significant submerged archaeological resources will eventually be outside the federal boundary and possibly open for salvage.

Although some research has been undertaken at CACO archeological sites, comprehensive inventories of archaeological resources within the park are still needed to prevent their loss or alteration; detailed attention should be given to sites where historic structure conservation could result in ground disturbance and to the offshore portions of National Register properties, while they are still under federal jurisdiction and relatively easy to locate.

Ethnography

The outer Cape possesses a unique heritage drawn from the culture of its original native peoples, the arrival of the Pilgrims and European settlers, the whaling and fishing industries, and from the many artists and writers who have been inspired by the stark beauty of Cape Cod. Cape Cod National Seashore was created in part to help preserve this heritage, and to celebrate it. In 1995, a preliminary ethnographic survey of the outer Cape identified several Cape Cod cultural communities, including Wampanoag, Portuguese and Cape Verdeans, and a number of customary Cape activities, including beachcombing, shellfishing, fishing, mushroom harvesting and berry picking.

A systematic, in-depth documentary study of the material and expressive culture of outer Cape Cod is still needed in order to gain a better understanding of what to preserve and foster within the park.

Cranberry Bog Restoration.

Background.

Once referred to as "red gold" by residents of Cape Cod, cranberry bogs are an integral part of the Cape's cultural landscape. The indigenous fruit thrives in nutrient-poor, acidic, waterlogged,

sandy loam soils (Brownlow, 1979) like those on the outer Cape, and was an important staple for native Americans and early European settlers. In later years, the cranberry (*Vaccinium macrocarpon*) also became a vital source of vitamin C for ship-bound whalers and fishermen. Cultivation of the berry began on the Cape in the early nineteenth century, and cranberry bogs quickly grew into a valuable financial resource for nineteenth- and early twentieth-century Cape Codders. Today, Cape Cod still produces ten percent of the state's cranberry harvest, although no working commercial bogs currently exist within Cape Cod National Seashore. An abandoned bog in the upper reaches of the Pamet River valley that served as a commercial cranberry farm for several Cape Cod families from the 1800s through the 1950s could, however, provide a valuable glimpse into the area's rich cultural and natural history if restored to working condition.

Research Needs.

Restoring the Pamet cranberry bog as a working example of the Cape's cranberry industry also means altering the current vegetative regime and restoring the area's earlier hydrology, which was altered by the construction of Route 6 and, more specifically, by the subsequent change in the level of the Pamet River. The water table in working bogs is controlled by extensive irrigation and drainage ditches, however, and restoration of these hydrological practices may in fact re-expose heavy metals used in the past as pesticides. The hydrology of this unique farmland needs to be analyzed to determine the extent of hydrologic restoration necessary, as well as the potential for toxic metals release. Based on this analysis, plans should be developed for managing the bog in a way that does not mobilize these metals. Research into the potential ecological impact of vegetation changes stemming from restoration is also needed.

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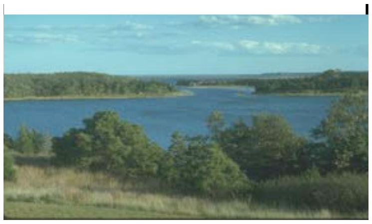
Vista Management.

Background.

When Cape Cod National Seashore was established in 1961, the early successional forest that



dominated much of the outer Cape provided many views, vistas and overlooks that were incorporated into the design of many buildings and trails within the park. Facilities such as the Salt Pond and Province Lands Visitor Centers, the Hemenway and Pilgrim Springs overlooks and the Eastham and Provincetown bicycle trails were located to take advantage of these expansive and splendid views, and to thereby foster a sense of public appreciation for the Cape's natural land- and seascapes. During the last forty years, growing vegetation has blocked many of the views afforded by the early forest. Specific views from visitor centers and some trails have been periodically maintained through the removal of trees and shrubs by work crews; in the absence of a long-term management plan, however, maintenance efforts have been sporadic and, in some cases, uninformed. In order to ensure that vista maintenance within the seashore is scientifically sound and executed on a regular basis, specific guidelines for vista maintenance and enhancement need to be outlined in a comprehensive management plan.

Research Needs.

Inventory Current and Historic Vistas: Creation of a Geographic Information Systems database showing current and documented historic vistas is needed to inform future management decisions regarding vista maintenance.

Develop Vista Management Plan: A vista management plan is needed which provides for the preservation of specific views developed by the original CACO planners, establishes criteria for the construction of new overlooks and prescribes methods for, and guidelines for the frequency of, routine vista maintenance.

Social Values Survey.

Background.

The essence of sustainable ecosystem management at Cape Cod National Seashore is the creation of a balance between its physical, biological and human elements; the goal is to provide opportunities for people to experience the outer Cape's incredible natural beauty while at the same time protecting its natural and cultural resources for generations to come. Since the conservation of the park's ecosystems requires the sustained participation of the people who visit them, information about the traditional and changing perceptions, beliefs, attitudes, behaviors, needs and values of both local residents and park visitors is vital to successful, sustainable resource management. Indeed, the most powerful tool for resource protection is not the park boundary, but policies and reform that make conservation a matter of private and public interest.

Research Needs.

A social values survey documenting the demographics, knowledge, activities and attitudes of local citizens and park visitors towards CACO resource management practices is needed to develop effective, educational and politically and socially acceptable solutions to ecological problems that may be exacerbated (or resolved) by visitor actions. The study should, at a minimum, address the ecological role of fire in CACO's plant communities, salt marsh restoration, off-road vehicle use, threatened and endangered species, human disturbance to wildlife and vegetation, and the management of exotic or overabundant native plants and animals; additional objectives and content areas should be defined through careful review of the park's General Management Plan, consultation with CACO natural and cultural resources staff and outside natural and social scientists, and discussion with local citizens. In addition to addressing social response to park management, the study should also identify where and how best to apply environmental education efforts in order to effectively modify attitudes and behaviors of local residents and the park's recreational users for resource protection.

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Resource Protection, Planning and Maintenance

Oil Spill Response.

Background.

With a major shipping lane located just six miles offshore, intensive commercial fishing activity as close as ten miles to the north, and major ports just across Cape Cod Bay, the probability of an oil spill impacting the resources of Cape Cod National Seashore is high; the presence of seven federally listed threatened and endangered species in CACO's offshore waters and seven more in the park's coastal areas, and the added presence of many large tankers, freighters, fishing and recreational vessels in the Gulf of Maine further confirm CACO's need for spill preparedness. There were at least thirteen major oil spills in the waters surrounding Cape Cod from 1969-1980 (Robinson, 1980) and several more in the late 1980s, two of which occurred in or near salt marshes. In addition, hundreds of small containers, many containing waste oil, wash onto CACO beaches every year. A Standard Operating Procedure for oil spills within the seashore was drafted in 1990, but a more detailed plan is needed for the evaluation and mitigation of spill impacts at CACO.

Research Needs.

An oil spill contingency and response plan needs to be developed in coordination with the United States Coast Guard. Oil spill booming priorities should be identified for park estuaries and beaches, with special consideration given to Nauset Marsh, the largest and least disturbed estuarine system within CACO and one with particular susceptibility to spills. A computer model of Nauset Marsh (developed by Friedrichs and Aubrey, 1989) may be useful for prescribing the locations and length of booms to best prevent resource damage in the estuary.

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Robinson, M.H. 1980. Cape Cod coastal oil spill response plan. Cape Cod Planning and Economic Development Commission. Barnstable, MA.

Potential Contaminant Source Identification.

Background.

The thin lenses of fresh groundwater that make up the Cape Cod aquifer are the outer Cape's sole source of potable water and the only hydrologic resource for freshwater dependent flora and fauna within Cape Cod National Seashore. Because the sandy soils of the outer Cape are highly permeable, even a small spill of hazardous waste could easily penetrate the aquifer, with potentially drastic and lengthy effects on the area's water supply. In 1978, 3,000 gallons of gasoline leaked from an underground storage tank near the South Hollow Wellfield, the main source of water for Provincetown at the time. As a result of the leak, the wellfield became completely unusable for two years and provided only one-fourth of its former capacity for five more, not returning to full capacity until nine years after it was contaminated. More recently, cracked fuel storage tanks at a lower Cape gas station resulted in hydrocarbon and MTBE groundwater contamination, including that under National Park Service lands, and another local business dumped mercury-based fungicide on NPS property resulting in a $30,000 cleanup. A contaminant survey of CACO salt marshes additionally revealed elevated PCB levels in a Provincetown marsh that, historically, should have had no source for PCB contamination. Although contamination incidents on the lower Cape are not likely to approach the type of massive problem that exists around the closed Edwards Air Force Base on the upper Cape, where a plume of various contaminants is working its way towards a major population area with no alternative water sources, the decade-long repercussion from the relatively small Provincetown leak and the continuing impacts to CACO resources from contaminants originating outside park boundaries nonetheless demonstrate a strong need for risk assessment and spill preparedness within the seashore.

Research Needs.

Evaluate Potential Contamination Sources: Numerous potential sources of contamination exist on the outer Cape, both within and outside of the park boundaries, and an evaluation of their threat to CACO water resources is critically needed. Information on location, type and size of potential source areas should be entered into CACO's Geographic Information System; when coupled with hydrogeological modeling, this GIS data should provide a means for risk assessment based on quantity and proximity to water resources. Potential contaminant sources should additionally be prioritized in order to determine which sites present the greatest hazards.

Develop a CACO-Specific Emergency Response Plan: Emergency response plans for hazardous waste impacts to CACO resources and for providing emergency water in the event of a spill outside the park boundaries need to be developed. Specific policy decisions should be detailed for various scenarios, with the input and approval of CACO resource managers. Given the number of seasonal visitors to the seashore and the lower Cape, plans should be developed not only for known contaminant sources but also for accidental spills.

Septic Systems.

Background.

Nearly all of the homes and businesses on the outer Cape, including a number of seasonal and, increasingly, year-round residences on kettle pond shorelines within Cape Cod National Seashore, rely on septic systems for solid waste disposal. For over two decades, various reports have documented increases in nitrate and phosphorous concentrations in the groundwater on the outer Cape, directly linking the elevated levels with increases in housing density and the number of actively used on-site septic systems (including Frimpter and Gay, 1979; Persky, 1986; Noss, 1989; Goetz et al., 1991; Portnoy et al. 1998). The addition of nitrogen and phosphorous via contaminated groundwater discharge into Cape Cod's pond, estuary and salt marsh surface waters is a major management concern at CACO; increased algae production spurred by the input of these nutrients reduces water clarity and quality, deprives bottom-dwelling flora and fauna of sunlight and ultimately strips the water of oxygen, creating the potential for massive fish and shellfish kills due to anoxic conditions.

Title 5 (Massachusetts law 310 CMR 15, Requirements for the Disposal of Sanitary Sewage) regulates the siting, design and construction of on-site below-ground septic systems in Massachusetts, requiring that an inspection of the existing septic system be performed any time a property is sold, expanded or altered in its use. The regulation also requires that soil absorption systems maintain a 400-foot distance from surface drinking water supplies, a 100-foot separation from wells and a 50-foot distance from rivers, lakes, ponds and wetlands. Additionally, a 4-foot zone of unsaturated soil (5 feet in sandy soils) above the high groundwater level is mandated in order to allow for the removal of pathogenic biological pollutants before they reach the groundwater (Janik, 1987; Weiskel et al., 1996). Even when operating properly under ideal conditions, however, all conventional septic systems leach nitrogen into the groundwater. A minimum lot size of 40,000 square feet is needed to effectively dilute the nitrogen contribution of a single-family septic system to concentrations below the Barnstable County planning guideline of 5 mg/L (Veneman, unpublished). In areas where this minimum lot size is unfeasible, alternative septic technologies, such as recirculating sand filters, peat filters and the RUCK system, have shown potential for increased nitrogen removal; such technologies have yet to be significantly utilized, however, on the outer Cape.

The seasonal nature of population densities on Cape Cod provides an additional complication to the problem of nutrient loading from septic systems. Postma et al. (1992) reported that after a septic system operates for 8 to 15 months, the continuous supply of wastewater to a conventional system produces a biological clogging mat that slows the rate at which effluent travels into the soil, promoting an even distribution of effluent throughout the treatment field and enhancing the system's ability to filter pollutants. The seasonal use of a septic system prevents the formation of this clogging mat, leading to uneven effluent distribution and a subsequent reduction in the system's ability to efficiently remove pollutants. Furthermore, in the absence of a clogging mat, septic

Septic Systems, continued.

effluent travels largely undiluted through the sandy, porous soils of the outer Cape; this concentrated, localized effluent path receives little treatment before reaching groundwater.

Given the porous nature of Cape Cod's groundwater aquifer, the intensity of the recreation in, on and around CACO's kettle ponds and other surface water bodies and the inherent biological fragility of these water resources, protecting freshwater and brackish habitats from the impacts of on-site septic systems has become one of the most complicated and important management programs at CACO. With concerns for apparent eutrophication caused by human-induced nutrient loading, an intensive annual water quality monitoring program has been ongoing at CACO's kettle ponds for the last nine years. Research on alternative methods of wastewater disposal is still needed, however, to mitigate the impacts of septic effluent on CACO water resources and to develop a sustainable balance between an increasing human presence and healthy groundwater on the outer Cape.

Research Needs.

Review Alternative Methods of Wastewater Disposal: As an initial step towards reducing septic system impacts on CACO's water resources, a literature review of potential alternative methods for wastewater disposal on the outer Cape needs to be conducted. Specific areas of investigation should include alternative technologies for private septic systems, cluster or package treatment plants for selected areas and increased on-line sewage, with information on cost, maintenance requirements, effectiveness, conditions for use (seasonal vs. year-round) and user reaction compiled for each. The feasibility of developing alternative septic technology for CACO facilities should also be evaluated, in part by comparing the available information on alternative technologies to facility requirements within the park.

Develop Case Studies of Improved or Alternative Septic Systems: Once the above literature review has been completed, at least two case model studies should be developed to demonstrate and evaluate appropriate systems for wastewater disposal within CACO. Ideally, one of these would be seasonally occupied, the other year-round, and both in close proximity to a kettle pond. Information then needs to be collected on actual installation costs, maintenance requirements, treatment efficacy and user reaction to the new technologies. Changes in nutrient transport resulting from use of the new system should be determined through the installation and monthly sampling of several shallow wells with 1 to 5-foot screened intervals, both before and for at least one year after the new system is installed.

(See related project descriptions under "Kettle Ponds," in the Aquatic Ecology chapter.)

Septic Systems, continued.

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Water Efficiency in Park Facilities.

Background.

Cape Cod National Seashore has three types of properties within its boundaries: park-owned facilities that are operated and/or used by park staff and the general public, federally-owned homes that are privately occupied, and grandfathered private properties that will always exist in CACO, but will never fall under the ownership of the National Park Service unless donated or sold to the park. Though use and ownership issues differ among the approximately 700 improved properties within the seashore, all have a potential impact on CACO's aquatic resources. Nearly all of the homes and businesses on the outer Cape, including a number of seasonal and, increasingly, year-round residences on kettle pond shorelines within the seashore, rely on septic systems for solid waste disposal. The addition of nitrogen and phosphorous via contaminated groundwater discharge from septic systems into Cape Cod's pond, estuary and salt marsh surface waters is a major management concern at CACO; increased algae production spurred by the input of these nutrients reduces water clarity and quality, deprives bottom-dwelling flora and fauna of sunlight and ultimately strips the water of oxygen, creating the potential for massive fish and shellfish kills due to anoxic conditions.

Quantity, as well as quality, of the outer Cape's fresh groundwater is also a concern. The thin lenses of fresh groundwater that make up the Cape Cod aquifer are the outer Cape's sole source of potable water and the only hydrologic resource for freshwater dependent flora and fauna within the seashore. The only source of freshwater to these lenses is precipitation; excessive water use during a dry year could thus damage plant and animal communities in wetlands and along pond shorelines.

Water conservation has occurred within the park to some degree. Low-flow showerheads have been installed in all of the houses that are owned and occupied by NPS staff, and low-flush toilets have been placed in some of the seasonal homes. On a more public scale, CACO has worked collaboratively with the Town of Provincetown to educate residents and visitors about water conservation. Water conservation strategies still need to be implemented more vigorously throughout the park, however, not only to minimize park impacts to resources, but also to serve as a working model of water conservation techniques for the park's many visitors and residents.

Research Needs.

Update Infrastructure Inventory: The existing inventory of water- and wastewater-related structures within the park, including underground storage tanks, needs to be updated to eliminate incorrect, incomplete or missing information. Since all improved properties have the potential to impact water resources, all improved properties within the park's boundaries should be inventoried, regardless of ownership status. Information relevant to a water resource risk assessment should be gathered for each

Water Efficiency in Park Facilities, continued.

structure, and the location of each facility or house should be recorded in a parkwide Geographic Information System data layer.

(See related projects under “Potential Contaminant Source Identification” and, in the Natural Resource Management chapter, “Land Use Mapping.”)

Monitor Water Efficiency: Flow meters need to be installed in each CACO facility, and research conducted to evaluate the effects of different plumbing hardware and behavioral approaches to water conservation.

Assess Risk to Water Resources: Based on the information gathered in the above projects, an assessment of the risk to CACO water resources from existing infrastructure and housing needs to be developed. Water resource-based criteria should be developed for the management of CACO homes and facilities, and appropriate strategies should be recommended for encouraging similar water-conscious management of private in-holdings.

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APPENDICES

United States Department of the Interior
National Park Service

APPLICATION PROCEDURES AND REQUIREMENTS FOR SCIENTIFIC RESEARCH AND COLLECTING PERMITS

POLICY AND GENERAL REQUIREMENTS

The National Park Service (NPS) welcomes your interest in considering national parks for your research site. The NPS is responsible for protecting in perpetuity and regulating use of our National Park areas (parks, monuments, battlefields, seashores, recreation areas, etc.). Preserving park resources unimpaired and providing appropriate visitor uses of parks require a full understanding of park natural resource components, their interrelationships and processes, and visitor interests that can be obtained only by the long term accumulation and analysis of information produced by science. The NPS has a research mandate to provide management with that understanding, using the highest quality science and information. Superintendents increasingly recognize that timely and reliable scientific information is essential for sound decisions and interpretive programming. NPS welcomes proposals for scientific studies designed to increase understanding of the human and ecological processes and resources in parks and proposals that seek to use the unique values of parks to develop scientific understanding for public benefit.

When is a permit required?

A Scientific Research and Collecting Permit is required for most scientific activities pertaining to natural resources or social science studies in National Park System areas that involve fieldwork, specimen collection, and/or have the potential to disturb resources or visitors. When permits are required for scientific activities pertaining solely to cultural resources, including archeology, ethnography, history, cultural museum objects, cultural landscapes, and historic and prehistoric structures, other permit procedures apply. The park's Research and Collecting Permit Office or Headquarters can provide copies of NPS research-related permit applications and information regarding other permits. Federally funded collection of information from the public, such as when formal surveys are used, may require approval from the Office of Management and Budget.

NPS superintendents may authorize their staff to carry out official duties without requiring an NPS research and collecting permit. NPS staff must comply appropriately with professional standards and with all conditions normally associated with scientific research and collecting permits issued by the park. All other natural and social science research and data collection in a park requires a Scientific Research and Collecting Permit and will be allowed only pursuant to the terms and conditions of the permit.

Additional required permits, approvals, and agreements

In some cases, other federal or state agency permits or approvals may be required before NPS staff can process an application for a Scientific Research and Collecting Permit. Examples include U.S. Fish and Wildlife Service threatened and endangered species permits and migratory bird permits and approvals by an Institutional Animal Care and Use Committee. It is the responsibility of the principal investigator to provide NPS with copies of such permits when they submit an application. Applicants are encouraged to contact park staff to determine if additional permits may be required in conjunction with a proposed study.

Separate agreements between the investigator and NPS are required when proposed studies or collected specimens are intended to support commercial research activities.

Who may apply?

Any individual may apply if he/she has qualifications and experience to conduct scientific studies or represents a reputable scientific or educational institution or a federal, tribal, or state agency.

When to apply?

We recommend that you apply at least 90 days in advance of your first planned field activities. Projects requiring access to restricted locations or proposing activities with sensitive resources, such as endangered species or cultural sites, usually require extensive review and can require 90 days or longer for a permitting decision. Simple applications can often be approved more quickly.

How and where to apply?

An individual may obtain application materials via the Internet (find "Research Permit and Reporting System" at http://science.nature.nps.gov/research or through www.nps.gov) or by contacting the park in which the work will be conducted. Addresses for NPS areas are listed on the NPS Internet web site (www.nps.gov) or may be obtained by contacting the NPS Public Affairs Office via telephone number 202-208-4747. All application materials must be submitted to the NPS area in which you plan to work. You may submit this information via Internet or traditional postal service.

Study proposals

Applications for Research and Collecting Permits must include a research proposal. Proposals must include, as appropriate, all elements outlined in the separate document *Guidelines to Researchers for Study Proposals.*

Review of proposals

Each proposal will be reviewed for compliance with National Environmental Policy Act (NEPA) requirements and other laws, regulations, and policies. The superintendent may also require internal and/or external scientific review, depending on the complexity and sensitivity of the work being proposed and other factors. You can expedite review of your proposal by providing photocopies of existing peer reviews, or by providing names, mailing addresses, and email addresses of persons that you wish to recommend to review your proposal. Specific details about the review process may be included with the application materials provided by that park.

Facilitating a favorable decision

The superintendent makes a decision to approve a research and collecting permit based on an evaluation of favorable and unfavorable factors (see examples, below), and on an assessment of perceived risks and benefits. While park managers will work with applicants to arrive at a mutually acceptable research design, there may be activities where no acceptable mitigating measures are possible and the application may be denied.

The time and effort required to review the permit application and accompanying study proposal will be proportional to the type and magnitude of the proposed research. For example, a single visit for a non-manipulative research project will often require a relatively simple proposal and the permitting decision should be relatively fast. A highly manipulative or intrusive investigation, however, with the potential to affect non-renewable, rare, or delicate resources, needing detailed planning or logistics, would receive more extensive review. Some of the predisposing factors that influence permitting decisions are outlined below.

Favorable factors

The proposed research:
- contributes information useful to an increased understanding of park resources, and thereby contributes to effective management and/or interpretation of park resources; provides for scheduled sharing of information with park staff, including any manuscripts, publications, maps, databases, etc., which the researcher is willing to share;
- addresses problems or questions of importance to science or society and shows promise of making an important contribution to humankind's knowledge of the subject matter;
- involves a principal investigator and support team with a record of accomplishments in the proposed field of investigation and with a demonstrated ability to work cooperatively and safely, and to accomplish the desired tasks within a reasonable time frame;
- provides for the investigator(s) to prepare occasional summaries of findings for public use, such as seminars and brochures;
- minimizes disruption to the park's natural and cultural resources, to park operations, and to visitors;
- discusses plans for the cataloging and care of collected specimens;
- clearly anticipates logistical needs and provides detail about provisions for meeting those needs; and
- is supported academically and financially, making it highly likely that all fieldwork, analyses, and reporting will be completed within a reasonable time frame.

Unfavorable factors

The proposed research:
- involves activities that adversely affect the experiences of park visitors;
- shows potential for adverse impact on the park's natural, cultural, or scenic resources, and particularly to non-renewable resources such as archeological and fossil sites or special-status species (the entire range of adverse impacts that will be considered also includes construction and support activities, trash disposal, trail conditions, and mechanized equipment use in sensitive areas);
- shows potential for creating high risk of hazard to the researchers, other park visitors, or environments adjacent to the park;
- involves extensive collecting of natural materials or unnecessary replication of existing voucher collections; requires substantial logistical, administrative, curatorial, or project monitoring support by park staff; or provides insufficient lead time to allow necessary review and consultation;
- is to be conducted by a principal investigator lacking scientific institutional affiliation and/or recognized experience conducting scientific research; and
- lacks adequate scientific detail and justification to support the study objectives and methods.

Park response

The principal investigator should receive notice of the approval or rejection of the application by written correspondence via mail, electronic mail, or facsimile. If modifications or changes in a study proposal initially deemed unacceptable would make the proposal acceptable, the park may suggest them at this time. If the application is rejected, the applicant may consult with the appropriate NPS Regional Science Advisor to clarify issues and assess the potential for reconsideration by the park.

Permittee response

If your permit request is approved by the park, you will receive a copy of the permit that you must sign and return to the park via mail or fax. Once the park receives a copy of the permit that you have signed, appropriate NPS officials will validate it and return an approved copy to you. You must carry a copy of the approved permit at all times while performing your research or collecting in the park.

Permit stipulations

General Conditions (requirements and restrictions) will be attached to all Research and Collecting Permits issued. These conditions must be adhered to by permit recipients. Additional Park-specific Conditions may also be included that address unique park resources or activities. An NPS permit is valid only for the activities authorized in the permit. The principal investigator must notify the NPS in writing of any proposed changes. Requests for significant changes may necessitate re-evaluation of the permit conditions or development of a revised proposal.

Access permit requirements

Some NPS areas require access permits for off-road travel, camping, and other activities. Access to many areas is limited and popular destinations can be booked several months in advance. Please contact the park's Research and Collecting Permit Office to obtain information on any needed access permits.

Research products and deliverables

Researchers working in NPS areas are required to complete an NPS Investigator's Annual Report form for each year of the permit, including the final year. The NPS maintains a system enabling researchers to use the Internet to complete and submit the Investigator's Annual Report. NPS staff will contact permit holders near the beginning of each calendar year to request the prior year's report and explain how to access and use the system. Investigator's Annual Reports are used to consistently document accomplishments of research conducted in parks. Principal investigators are responsible for the content of their reports. NPS staff will not modify reports received unless requested to do so by the principal investigator responsible for the report.

Park research coordinators may request copies of field notes, data, reports, publications and/or other materials resulting from studies conducted in NPS areas. Additional deliverables may be required of studies involving NPS funding or participation.

Privacy Act and Paperwork Reduction Act

NPS regulations (36 CFR 2.1) prohibit possessing, destroying, injuring, defacing, removing, digging, or disturbing from their natural state in any form animals, plants, paleontological, or mineral resources. NPS regulations (36 CFR 2.5) require researchers wishing to conduct research involving acts prohibited by other regulations, such as CFR 2.1, to obtain a specimen collection permit. The National Parks Omnibus Management Act of 1998 (Public Law 105-391) encourages use of parks for science, encourages publication of the results of research conducted in parks, and requires that research conducted in parks be consistent with park laws and management policies. This law also requires that research be conducted in a manner that poses no threat to park resources or public enjoyment. National Park Service Management Policies state that research activities that might disturb resources or visitors, that require the waiver of any regulation, or that involve the collection of specimens may be allowed only pursuant to terms and conditions of an appropriate permit.

The information you submit in your Application for a Scientific Research and Collecting Permit will be used by park managers to determine whether or not to issue you a Scientific Research and Collecting Permit. The information you submit in your Investigator's Annual Report will be used by park managers to inform resource management decision-makers, park visitors, the public, and other researchers about the objectives and progress results of your research.

Parks and park records are public assets. The information you submit in your Application and in your Investigator's Annual Report is not confidential and will be in the public record and available to the public. If you want to receive and maintain a Scientific Research and Collecting Permit, you must respond to both the Application and Investigator's Annual Report collections of information. If you do not respond to the request for information in the Application, you will not be considered for a Scientific Research and Collecting Permit. If you have received a Scientific Research and Collecting Permit and do not respond to the request for information in the Investigator's Annual Report, your permit may be revoked and you may be denied future permits.

The Application for a Scientific Research and Collecting Permit and the Investigator's Annual Report are two parts of one complete process dealing with conducting scientific research and collecting in a unit of the National Park System. The total public reporting burden involved in electronically completing the collection of information process for a single scientific research and collecting activity in a unit of the National Park System includes the burden of reading the informational documents associated with these two information collection forms plus completing and submitting one Application form (approximately 45 minutes), plus the burden of signing and mailing an issued permit back to the park (approximately 15 minutes), plus the burden of completing one associated Investigator's Annual Report form (approximately 15 minutes). Some applicants will experience an additional burden of photocopying and mailing attachments (approximately 15 minutes). Other applicants will experience an additional burden of coordinating with a specimen repository (approximately 30 minutes). The total public reporting burden experienced by a successful permittee for electronically completing this process for a single scientific research and collecting activity in a unit of the National Park System thus is estimated to range between 1.25 and 2.0 hours per year. The total public reporting burden experienced by an unsuccessful applicant for electronically completing this process is estimated to be about 45 minutes per year because the unsuccessful applicant will not be required to complete the Investigator's Annual Report, mail a signed permit, or respond to other portions of the process. The few applicants who complete these forms manually are expected to experience a somewhat larger annual reporting burden. Direct any comments you may have regarding this burden estimate or any other aspect of this information collection process or of its two forms to the Office of Information and Regulatory Affairs of OMB, Attention Desk Officer for the Interior Department, Office of Management and Budget, Washington, DC 20503; and to the Information Collection Clearance Officer, WASO Administrative Program Center, National Park Service, 1849 C Street, N.W., Washington, DC 20240.

APPLICATION FOR A SCIENTIFIC RESEARCH AND COLLECTING PERMIT

United States Department of the Interior
National Park Service

Name of the National Park Service area(s) you are applying to:		
Select one of the following: [ ] New application [ ] Renewal of a previously issued permit [ ] Modification of a previously issued permit	Please enter numbers for permit renewal or modification requests: Previously assigned NPS study number: Previously assigned NPS permit number:	
Name of principal investigator (first, last)	Office phone #	
Mailing address of principal investigator	Alternative phone # Office FAX #	
Name of institution represented	Office email address of principal investigator	
Additional investigators (first name, last name, office phone, office email)		
Project title (maximum 300 characters)		
Purpose of study (maximum 4000 characters)		
Proposed starting date (month/day/year)	Proposed Ending date (month/day/year)	
Will members of the public be asked to participate in a survey as part of this proposed study? (Yes or No)		
Do you anticipate receiving funding assistance from the U.S. federal government for this study? (Yes or No) If "Yes," specify the agency(s):		
Where will data reside upon completion of this project?		
Location(s) where activities will take place within the National Park Service area(s):		
Method of access (vehicles, aircraft, boat, snowmobile, foot, etc.):		
Would you like to collect specimens or materials? (Yes or No)	**If you respond "Yes," please complete Page 2 of this application.**	

A research proposal on paper, or in electronic form, must accompany this application.

I certify that this application is accurate and complete. I authorize the National Park Service to seek peer reviews of my proposal.

Signature of principal investigator:________________________________ Date:

Park Service use only	Date received	Assigned study number	Assigned permit number

(This form continues on Page 2)

The National Park Service may not conduct or sponsor, and a person is not required to respond to, this collection of information unless it displays a currently valid OMB control number. **OMB#: (Requested)** **Expires: (Requested)**

APPLICATION FOR A SCIENTIFIC RESEARCH AND COLLECTING PERMIT

United States Department of the Interior
National Park Service

PAGE 2:
COLLECTIONS
(Complete this section if you would like to collect specimens or materials)

Scientific description of specimens or materials to be collected (include taxonomic group or name, or type of material; sample size, quantity, frequency, and location):

If you propose that specimens or materials are to be retained permanently, they will become part of National Park Service collections. You may request that they be loaned to or otherwise deposited with a non-NPS institution.
Proposed repository of specimens:

[ ] **National Park Service**
[ ] **Other institution (if selected, you must complete the box below)**
[ ] **Will be destroyed through analysis or discarded after analysis**

Proposed Repository for Collections
(Complete this section only if you checked "Other institution" in the box above)

Non- Non-NPS institution where specimens or materials are proposed to be deposited:

Organization Information

Institution: ______________________________

Address: ______________________________
____
____
____

Phone #: ______________________________
FAX #: ______________________________
Email: ______________________________

This organization concurs with the proposal that collected specimens or materials be loaned or deposited to this institution subject to the "General Permit Conditions and Restrictions" and the terms of applicable National Park Service loan agreements.

______________________________ ______________
(Signature of responsible official at custodial institution) **(Date)**

______________________________ ______________________________
(Name of responsible official – please print) **(Title of responsible official – please print)**

GUIDELINES TO RESEARCHERS FOR STUDY PROPOSALS

United States Department of the Interior
National Park Service

Your proposal should include each of the required information items listed below, in enough detail that an educated non-specialist can understand exactly what you plan to do. If you have already prepared a relevant proposal for a funding application, work plan, formal agreement, or similar document, then your original proposal likely will satisfy National Park Service (NPS) proposal requirements. The primary area where new information may be necessary concerns the ability of the park to assess what, if any, impacts your research may have on park resources. You should compare your original proposal to these guidelines to be certain that you have provided all the required information. If additional information is required, you can provide it in a cover letter or supplement to your proposal, as appropriate. If a required topic does not apply to your proposed study, simply list the topic and write "not applicable."

The length of your proposal depends primarily on the complexity of the work planned. In some cases, a proposal may consist of a couple of pages for a study expected to have no significant impact on park resources or visitor experiences. However, proposals for lengthy or complex research problems, for extensive collecting, and for work with special status species or sensitive cultural resources are typically longer, more detailed, and well-organized. Incomplete, disorganized, or illegible proposals may be returned for revision.

I. INTRODUCTION

A. **Title**

B. **Date of proposal**

C. **Investigators -** Provide the name, title, address, telephone number, FAX number, email address, and institutional affiliation of the principal investigator and the name and affiliation of all additional investigators listed in the proposal.

D. **Table of contents** - Recommended for long or complicated proposals.

E. **Abstract** - Provide a brief summary description of the proposed project. Include up to five keywords that can be used by the NPS to quickly identify the proposal subject (for example, microbiology, geology, ecology).

II. OVERVIEW - Summarize the proposed project by describing in general the problem or issue being investigated as well as any previous pertinent research.

A. **Statement of issue** - Describe the issue to be investigated and its importance and relevance to science and to the park. Provide relevant background information that clarifies the need for the project and why it is valuable for the research and/or collecting to be conducted in the park.

B. **Literature summary** - Summarize the relevant literature regarding the issue, problem, or questions that will be investigated.

C. **Scope of study** - Describe the overall geographic and scientific scope of the project.

D. **Intended use of results** - Describe how the products will be used, including any anticipated commercial use.

III. **OBJECTIVES/HYPOTHESES TO BE TESTED** - Describe the specific objectives of the proposed project. Where appropriate, the objectives should be stated as specific hypotheses to be tested.

IV. **METHODS** - Describe how the proposed methods and analytical techniques will achieve the study objectives or test the stated hypothesis/question. Provide pertinent literature citations.

A. **Description of study area** – Clearly describe the study area in terms of park name(s), geographic location(s), and place names. Provide maps, park names, or geographic coordinates as appropriate. Indicate whether your work will take place in an area designated or managed as “wilderness” by the NPS.

B. **Procedures** - Describe the proposed study design that addresses the stated objectives and hypotheses. Explain the methods and protocols to be employed in the field and laboratory.

C. **Collections** - Describe the type, size, and quantity of specimens or materials to be collected, sampled, or captured, and your plans to remove them from the collecting site. If you are aware specimens of the proposed types already exist in a repository, explain why additional collecting is necessary. Provide scientific nomenclature where possible. Provide information on all other applicable federal or state permits where required.

D. **Analysis** - Explain how the data from the study will be analyzed to meet the stated objectives or test the hypotheses. Include any statistical techniques or mathematical models necessary to the understanding of the analysis.

E. **Schedule** - Provide a schedule that includes start of project, approximate dates or seasons of fieldwork, analysis, reporting, and completion dates.

F. **Budget -** Briefly outline the expenses associated with this project and identify your expected funding source(s). Include the anticipated costs pertaining to the cataloging of collected and permanently retained specimens or materials.

V. **PRODUCTS**

A. **Publications and reports** - Describe the expected publications or reports that will be generated as part of this study.

B. **Collections** – Describe the proposed disposition of collected specimens or materials. If you propose that the NPS lend the specimens or samples to a non-NPS institution for long-term storage, identify that institution and give a brief justification for this proposal.

C. **Data and other materials** - Describe any other products to be generated as part of the project, such as, photographs, maps, models, handouts, exhibits, software presentations, raw data, GIS coverages, or videos, and the proposed disposition of these materials. If data are to be collected from the public as part of this study, provide a copy of the data collection instrument (survey, questionnaire, interview protocol, etc.).

VI. **LITERATURE CITED** - Include full bibliographic citations for all reports and publications referenced in the proposal.

VII. **QUALIFICATIONS -** Provide a background summary or curriculum vitae for the principal investigator and other investigators listed in the proposal. Identify their training and qualifications relevant to the proposed project and their ability to conduct field activities in the environment of the proposed study area. Describe previous research and collecting in NPS areas, including study and permit numbers if available.

VIII. **SUPPORTING DOCUMENTATION AND SPECIAL CONCERNS** - Provide information on the following topics where applicable. Attach copies of any supporting documentation that will facilitate processing of your application, such as other required federal and state permits, copies of peer reviews, letters of support and funding commitments, and certifications. Collection of information from the public when federal funds are used may require approval from the Office of Management and Budget (OMB). Upon your request, the NPS Social Science Program will advise you on steps needed to obtain this OMB approval.

A. **Safety** - Describe any known potentially hazardous activities, such as electrofishing, rock climbing, scuba diving, whitewater boating, aircraft use, wilderness travel, wildlife capture, handling or immobilization, use of explosives, etc.

B. **Access to study sites** - Describe the proposed method and frequency of travel to and within the study site(s). Explain any need to enter restricted areas. Describe duration, location, and number of participants for planned backcountry camping.

C. **Use of mechanized and other equipment** - Describe any field equipment, markers, or supply caches by type, number, and location. You should explain how long they are to be left in the field. Explain the need to use these materials in restricted areas and the alternatives that were considered.

D. **Chemical use** - Identify any chemicals and hazardous material that you propose using within the park. Indicate the purpose, method of application, and amount to be used. Describe plans for storage, transfer, and disposal of these materials and describe steps to remediate accidental releases into the environment. Attach copies of Material Safety Data Sheets.

E. **Ground disturbance** - Describe the type, location, area, depth, number, and distribution of expected ground-disturbing activities, such as soil pits, cores, stakes, or latrines. Describe plans for site restoration of significantly affected areas.

Proposals that entail ground disturbance may require an archeological survey and special clearance prior to approval of the study. You can help reduce the extra time that may be required to process such a proposal by including identification of each ground disturbance area on a USGS 7.5-minute topographic map.

F. **Animal welfare** - For vertebrate species that require review by your Institutional Animal Care and Use Committee (IACUC) according to the Animal Welfare Act, please include a photocopy of the study protocol, and IACUC review form and approval.

For vertebrate species not requiring IACUC review, describe your protocol for any capture, holding, marking, tagging, tissue sampling, or other handling of these animals (including the training and qualifications of personnel relevant to animal handling and care). Please discuss alternative techniques considered and outline any procedures to alleviate pain or distress. Include contingency plans to be implemented in the event of accidental injury to or death of the animal.

G. **NPS assistance** - Describe any NPS field assistance you would like to receive to complete the proposed study, such as use of equipment or facilities or assistance from staff.

H. **Wilderness “minimum requirement” protocols** - If some or all of your activities will be conducted within a location administered by the NPS as a designated, proposed, or potential wilderness area, your proposal should describe how the project adheres to wilderness “minimum requirement” and “minimum tool” concepts. Refer to the park’s wilderness management plan for further information.

GENERAL CONDITIONS
For
SCIENTIFIC RESEARCH AND COLLECTING PERMIT

United States Department of the Interior
National Park Service

1. **Authority** - The permittee is granted privileges covered under this permit subject to the supervision of the superintendent or a designee, and shall comply with all applicable laws and regulations of the National Park System area and other federal and state laws. A National Park Service (NPS) representative may accompany the permittee in the field to ensure compliance with regulations.

2. **Responsibility** - The permittee is responsible for ensuring that all persons working on the project adhere to permit conditions and applicable NPS regulations.

3. **False information** - The permittee is prohibited from giving false information that is used to issue this permit. To do so will be considered a breach of conditions and be grounds for revocation of this permit and other applicable penalties.

4. **Assignment** - This permit may not be transferred or assigned. Additional investigators and field assistants are to be coordinated by the person(s) named in the permit and should carry a copy of the permit while they are working in the park. The principal investigator shall notify the park's Research and Collecting Permit Office when there are desired changes in the approved study protocols or methods, changes in the affiliation or status of the principal investigator, or modification of the name of any project member.

5. **Revocation** - This permit may be terminated for breach of any condition. The permittee may consult with the appropriate NPS Regional Science Advisor to clarify issues resulting in a revoked permit and the potential for reinstatement by the park superintendent or a designee.

6. **Collection of specimens (including materials)** - No specimens (including materials) may be collected unless authorized on the Scientific Research and Collecting permit.

The general conditions for specimen collections are:

- Collection of archeological materials without a valid Federal Archeology Permit is prohibited.
- Collection of federally listed threatened or endangered species without a valid U.S. Fish and Wildlife Service endangered species permit is prohibited.
- Collection methods shall not attract undue attention or cause unapproved damage, depletion, or disturbance to the environment and other park resources, such as historic sites.
- New specimens must be reported to the NPS annually or more frequently if required by the park issuing the permit. Minimum information for annual reporting includes specimen classification, number of specimens collected, location collected, specimen status (e.g., herbarium sheet, preserved in alcohol/formalin, tanned and mounted, dried and boxed, etc.), and current location.
- Collected specimens that are not consumed in analysis or discarded after scientific analysis remain federal property. The NPS reserves the right to designate the repositories of all specimens removed from the park and to approve or restrict reassignment of specimens from one repository to another. Because specimens are Federal property, they shall not be destroyed or discarded without prior NPS authorization.
- Each specimen (or groups of specimens labeled as a group) that is retained permanently must bear NPS labels and must be accessioned and cataloged in the NPS National Catalog. Unless exempted by additional park-specific stipulations, the permittee will complete the labels and catalog records and will provide accession information. It is the permittee's responsibility to contact the park for cataloging instructions and specimen labels as well as instructions on repository designation for the specimens.
- Collected specimens may be used for scientific or educational purposes only, and shall be dedicated to public benefit and be accessible to the public in accordance with NPS policies and procedures.

- Any specimens collected under this permit, any components of any specimens (including but not limited to natural organisms, enzymes or other bioactive molecules, genetic materials, or seeds), and research results derived from collected specimens are to be used for scientific or educational purposes only, and may not be used for commercial or other revenue-generating purposes unless the permittee has entered into a Cooperative Research And Development Agreement (CRADA) or other approved benefit-sharing agreement with the NPS. The sale of collected research specimens or other unauthorized transfers to third parties is prohibited. Furthermore, if the permittee sells or otherwise transfers collected specimens, any components thereof, or any products or research results developed from such specimens or their components without a CRADA or other approved benefit-sharing agreement with NPS, permittee will pay the NPS a royalty rate of twenty percent (20%) of gross revenue from such sales or other revenues. In addition to such royalty, the NPS may seek other damages to which the NPS may be entitled including but not limited to injunctive relief against the permittee.

7. **Reports -** The permittee is required to submit an Investigator's Annual Report and copies of final reports, publications, and other materials resulting from the study. Instructions for how and when to submit an annual report will be provided by NPS staff. Park research coordinators will analyze study proposals to determine whether copies of field notes, databases, maps, photos, and/or other materials may also be requested. The permittee is responsible for the content of reports and data provided to the National Park Service.

8. **Confidentiality** - The permittee agrees to keep the specific location of sensitive park resources confidential. Sensitive resources include threatened species, endangered species, and rare species, archeological sites, caves, fossil sites, minerals, commercially valuable resources, and sacred ceremonial sites.

9. **Methods of travel** - Travel within the park is restricted to only those methods that are available to the general public unless otherwise specified in additional stipulations associated with this permit.

10. **Other permits** - The permittee must obtain all other required permit(s) to conduct the specified project.

11. **Insurance** - If liability insurance is required by the NPS for this project, then documentation must be provided that it has been obtained and is current in all respects before this permit is considered valid.

12. **Mechanized equipment** - No use of mechanized equipment in designated, proposed, or potential wilderness areas is allowed unless authorized by the superintendent or a designee in additional specific conditions associated with this permit.

13. **NPS participation** - The permittee should not anticipate assistance from the NPS unless specific arrangements are made and documented in either an additional stipulation attached to this permit or in other separate written agreements.

14. **Permanent markers and field equipment -** The permittee is required to remove all markers or equipment from the field after the completion of the study or prior to the expiration date of this permit. The superintendent or a designee may modify this requirement through additional park specific conditions that may be attached to this permit. Additional conditions regarding the positioning and identification of markers and field equipment may be issued by staff at individual parks.

15. **Access to park and restricted areas** - Approval for any activity is contingent on the park being open and staffed for required operations. No entry into restricted areas is allowed unless authorized in additional park specific stipulations attached to this permit.

16. **Notification** - The permittee is required to contact the park's Research and Collecting Permit Office (or other offices if indicated in the stipulations associated with this permit) prior to initiating any fieldwork authorized by this permit. Ideally this contact should occur at least one week prior to the initial visit to the park.

17. **Expiration date -** Permits expire on the date listed. Nothing in this permit shall be construed as granting any exclusive research privileges or automatic right to continue, extend, or renew this or any other line of research under new permit(s).

18. **Other stipulations** - This permit includes by reference all stipulations listed in the application materials or in additional attachments to this permit provided by the superintendent or a designee. Breach of any of the terms of this permit will be grounds for revocation of this permit and denial of future permits.

INVESTIGATOR'S ANNUAL REPORT
National Park Service

If you are not using the automated system supporting this report process, please fill out this form and return it to the appropriate park.
All or some of the information provided may be available to the public.

Reporting Year	Park

Principal Investigator Name (first, last) Dr. Ms. Mr. Mrs.	Office Phone
Address	Office FAX Office Email

Additional investigators (first name, last name, phone, email)

Project Title (maximum 300 characters)

Park-assigned Study #	Park-assigned Permit #	Permit Start Date	Permit Expiration Date

Study Starting Date	Estimated Study Ending Date

Study Status (*circle one*): Completed Continuing Suspended Terminated before completed

Activity Type (*circle one*): Research Inventory Monitoring Education Other

Subject/Discipline	Ecology	Geo. Info. System (GIS)	Ichthyology	Recreation/ Aesthetics	Volcanology/
(*circle one*):	Entomology	Geochemistry	Integrated Pest Mgmt.	Restoration – Cultural	Geothermal
	Environmental Monitoring	Geohydrology	Invertebrates	Restoration – Natural	Water Quality
Agriculture	Erosion/ Sedimentation	Geology – Coastal	Limnology	Sedimentology/ Stratigraphy	Water Quantity
Air Quality	Exotic Sp. – Animals	Geology – Fluvial	Mammalogy	Social Science – Economics	Water Rights
Anthropology/Ethnography	Exotic Sp. – Plants	Geology – General	Mgmt./ Administration	Social Science – Geography	Watershed Mgt.
Archeology	Fire	Geology – Structural	Microbiology	Social Science – History	Wetlands
Botany	Fisheries Management	Geomorphology	Minerals Management	Social Science – Sociology	Wildlife Management
Cave (Flora/ Fauna)	Flood Mgmt./ History	Geophysics	Oceanography	Social Science – Other	Zoology
Cave/ Karst	Forestry	Glaciology	Ornithology	Soil Science	
Climatology	Fungi	Herpetology	Paleontology	Tectonics	**Other**
Coastal/ Marine Systems	Geo-Hazard (Chemical)	Hydrology (Ground)	Petrology/ Mineralogy	Threat./ Endangered Animals	
Contaminants/ Haz. Mat.	Geo-Hazard (Physical)	Hydrology (Surface)	Range Management	Threat./ Endangered Plants	

Objectives (maximum 4000 characters)

Findings and Status (maximum 4000 characters)

Reports Produced (Reference Title, Authors, Name of Publication, Abstract, Volume and Page Numbers, Year Published, Type of Reference, Keywords)

For this study, were one or more specimens collected and removed from the park but not destroyed during analysis? (Y/N)
If "Yes," where are the specimens currently stored?

Funding provided this reporting year by NPS (enter dollar amount) $	Funding provided this reporting year by other sources (enter dollar amount) $

List other U.S. Government Agencies supporting this study and funding each provided this reporting year:

Fill out the following ONLY IF the National Park Service supported this project in this reporting year by providing money to a university or college

Full name of college or university	Name of department or program
Name of campus, if unique	Annual funding provided by NPS to university or college this reporting year $